Experimental study for leakage detection in subsea pipeline by applying acoustic emission technique

A.B.C. Ahmed M. Shama, Mohamed El-Shaib & Ashraf Sharara
Arab Academy for Science, Technology & Maritime Transport, Alexandria, Egypt
D. Yehia Nasser
Alexandria University, Alexandria, Egypt

ABSTRACT: Due to the increase in economy and population worldwide, the demand for oil and gas increased, most of which are transmitted through pipelines. One of the most challenging pipelines system operations is early detect any abnormal behavior that may lead to catastrophic accidents.

Acoustic emission (AE) technology is a sensitive passive listening technique, which can detect small crack growth events. It has been used in many applications, to obtain additional information on the different damage types.

In order to study the capability of the AE to monitor oil leakage, an experiment has been designed to simulate oil leakage in subsea pipeline for different defects sizes at different flow-rate speeds.

Different AE parameters such as energy, amplitude and number of counts have been used to distinguish between different conditions. Results show that AE is capable to identify different defects sizes at different flow-rate speed. In addition, the average frequency indicates the presence of the leak.

1 INTRODUCTION

Subsea steel pipelines are the commonly used means of oil transportation these days (Lam, 2015). Optimizing the industrial economics of oil and gas requires increasing their transported volume by utilizing pipelines with higher pressures and wider diameters. Therefore, depending on steel pipes should be greater than before to help in increasing several aspects; safety, environment protection, and financial outcomes as well. Dependency on steel pipes rises by increasing their strength and by better controlling pipeline leakage to protect the environment from the oil hazardous effects on sea creatures and on the marine ecosystem (Potters, 2013).

This paper starts with an introduction section to give an overview of leak detection systems of subsea pipelines, and then it discusses the AE signal’s characteristics. Afterwards, the paper explains the experimental model design and its installation in order to measure acoustic waves emitted from the pipeline. It concludes with an analysis section for the signal data and the attained results.

The classification of available leak detection techniques helps in selecting the optimum method of each case. Several criteria are taken into consideration for this classification, which could be divided into two methods of grouping depending on the amount of needed human intervention, the measured physical quantity or the technical nature of the methods(Murvay, 2012).

The first method considers the needed human intervention. Accordingly, the degree of intervention needed from a human by each detection method is chosen to distinguish these methods into the following categories: [automated / semi-automated / manual].

The second method of grouping and the most common one is to classify leak detection methods based on their technical nature, which divides them into two main categories and a minor one stated respectively: hardware-based methods, software-based methods, and biological methods (Henrie, 2016). The aforementioned categories are sometimes referred to as externally or internally based leak detection systems.

The implemented acoustic emission technique has the advantage of online continuous monitoring. It is considered effortless and it has the capability to detect leakage location (time dependent failure) in the pipeline(Datta and Sarkar, 2016). Also, the AE tech-
tique could use portable devices and it has high sensitivity as well (Sivathanu, 2004).

The AE system is a reliable technique to detect and locate leaks in subsea pipelines, but it requires access to the pipeline for the installation of AE sensors. The basic principle is that the pipe subjected to a leak will generate acoustic noise; this noise contains information that could be used to detect this leak and its location as well.

In his research, Millera used a reference standard system to study leakage from a 2 inches pipe diameter. This system was constructed for setting up and evaluating an AE equipment to be used in pipeline leakage detection (R. K. Millera, 1999). The reference standard system was proved very valuable not only for the assessment of the used equipment, but also for identifying source mechanisms as part of an integrated approach to quantitative AE leak detection/location technology.

Barbezat designed a model experiment for leakage testing for pipe segments, in order to explore potential acoustic emission applications of piezoelectric Active-Fiber-Composite (AFC) sensor elements made from piezoelectric fibers (Barbezat, 2007). A pipe segment made of aluminum with a diameter of 50 mm has been utilized with compressed air (gaseous medium) for a range of operating pressures (between 400 and 800 kPa). Leaks have been simulated by the use of screws to create holes of various diameters (between 0.1 to 1.2 mm). It was found that the measurement of AE signal was dependent on leak hole diameter (or more generally, leak geometry) besides the operating pressure of the tested pipe. It was also noticed that leaks generated additional contributions in the power spectrum of the recorded AE signals at frequencies between 150 - 160 kHz for both types of AE sensor.

Kaewkongka described the application of AE for monitoring pipeline condition by using pre-processed AE parameters and Gaussian distribution to identify characteristic features relative to each pipeline condition. In his experiments, two types of pipeline operating conditions were studied, an ordinary pipe and a defective pipe. Kaewkongka found that the signal obtained from the ordinary pipeline - operating in a good condition- yielded fewer amplitudes; around 0.1 Volts than the amplitudes yielded by the defected one. On the other hand, the defected pipeline having a microscopic crack generated transient amplitude (Tonphong Kaewkongka, 2007). Ahadi used a new method to detect leakage of a water-filled plastic pipe. In this method, the leakage signal in the time domain was first captured by monitoring the Short Time Fourier Transforms (STFT) of AE signals over a relatively long time interval. The captured signal was then used to find a mother wavelet (tuned wavelet) for the best localization of this signal in the time and frequency domains (Majid Ahadi, 2010).

Sun performed successive experiments which studied parameters such as pipe pressure, the leakage hole diameter, and the distance from transducers to the leakage hole. All the aforementioned parameters were adjusted to show influence on AE signals generated by the leak. These experiments aimed mainly to detect and locate the leakage in the pressurized pipeline. Both the detection and localization of the leakage were found insensitive to the geometry of the inspected pipe structure. Also, these experiments validated that the leak position could be detected through cross-correlation analysis of continuous AE signals (Liying Sun 2010).

Yoshida chose four types of artificial geometrical defects such as; straight, stepwise, truncated cone, and slit-type pinholes to measure the smallest possible flaws of the pipe material, which could be found in actual pipe installations. This study suggested the possibility to characterize the different AE signals generated during gas leakage. As a result, this could eventually develop the accuracy of the defect analysis during actual monitoring and inspection of pipelines (Kenichi Yoshida, 2010).

Liu proposed a new leak positioning method for oil and gas pipelines based on leakage’s acoustic waves. First, the dominant energy frequency bands of leakage acoustic waves were obtained through applying a wavelet transform analysis on the experiment. Then, the actual propagation model was modified by the correction factor; which was chosen based on the dominant energy frequency bands. Finally, a new leak detection and positioning method were proposed based on the propagation law which was validated by the implemented experiments (Liu et al., 2015).

Kaewkongka provided a method for utilizing the acoustic emission (AE) technique -which uses piezoelectric sensors- to detect leakage in the pipeline and locate its position. The signal conditioning unit was used to enhance and eliminate the background noise from the location of the leakage sources (Kaewkongka, 2016).

2 EXPERIMENTAL SETUP

In this experiment, a rig test was established; consisting of a closed loop of a metallic piping system (12 m total) for oil; pumped from an oil tank, then it passes through an acrylic water tank.

The rig is equipped with two piezoelectric AE sensors at each side, and flow meter beside a pressure gauge at the pipe’s entry side. A fixed base drill -with a standard diameter drill bit- is used to create a leak hole.

The rig is designed to detect the leakage using the acoustic emission sensors when the oil pipe is exposed to water that creates hydrostatic pressure; proportionally increasing by the increase of water depth.
The experimental rig layout is shown below in figure 1.

To start with, the oil pipe is in a sound condition and the measurements are taken first without any leakage. These measurements are kept as a reference. After that, leakage holes are drilled in the metallic pipe at a distance of 42.5 cm from sensor 1 by drilling 4 holes with different diameters; 1 mm, 2 mm, 3 mm, and 4 mm. The measurements are taken again with several oil flow rates (7 flowrates). The oil starts to flow with a flow rate of 11.5 liters per seconds, and then the motor speed decreases till the oil flow reaches 7.5 liters per seconds.

Therefore, the analysis of the recorded readings gives the indication of leakage presence. The two sensors are positioned on the metallic pipe, but outside the tank. To achieve the most accurate readings, the sensors are fixed in their positions under all the different reading cases.

The oil is pumped by a gear pump attached to a variable speed motor (1 hp) as the pipe length inside the water tank is 120 cm. The total length of the examined pipe is 170 cm. The parameters of the acoustic signal are defined as the following:
- Amplitude, A, is the greatest measured voltage in a waveform and is measured in decibels (dB).
- Counts, N, refer to the number of pulses emitted if the signal amplitude is greater than the threshold.
- Energy, E, is the measure of the area under the envelope of the rectified linear voltage time signal from the sensor and is measured in (J).
- Average frequency, f, the reciprocal of the average period computed over cycles of the event and is measured (Hz).

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Figure 2 indicates The AE acquisition system; consisting of an array of two sensors with their preamplifiers and a physical acoustics pocket AE system as a computerized hand-held instrument for AE testing and leak detection applications.

In addition, the AE Sensors and Pre-amplifier are used; the Pocket AE has a built-in internal AE preamplifier besides having the capability of operating a low power line of external preamplifiers and/or integral preamplifier sensors. These sensors allow for selecting between the use of internal or external pre-amplifier via a software (MISTRAS, 2007).

The pocket AE is attached to physical acoustic sensors (R15a). These sensors have built-in amplifiers and flat frequency responses with two bands of relatively high sensitivity -at around 50 kHz and 200 kHz- and they have an operating temperature ranging from -65°C to 177°C. The sensors are 19 mm in diameter, 22 mm high, and 34 gm weight. They are fixed onto the pipe surface using an adhesive tape to ensure a good contact of the AE element. The pipe surface was kept smooth and clean and silicone grease was used as a coupling to fill any gaps caused by surface roughness and to eliminate air gaps which might otherwise impair AE transmission (M. Abdel-Geliel, 2010).

Figure 3. Linear source location technique.

The simplest equation to calculate the leakage source location existing between two sensors could be expressed as:

$$X_2 = \frac{1}{2}(X + \Delta t V)$$

(1)

Where X is the distance between the two sensors, X1 is the distance from the leak location to the first sensor hit by the leakage acoustic waves, and X2 is the distance from the leak location to the other sensor.
The measurements are mainly analyzed by Noesis Software Package, which is used for data handling and signal processing (ABEE, 2011).

3 RESULTS AND ANALYSIS

A mechanical pencil lead break support or Hsu-Nielsen source (Nielsen, 1980) were applied to simulate an acoustic emission events using the fracture of a brittle graphite lead of a pencil with a 45° angle. The pencil lead should be the same type (0.3 or 0.5 mm diameter, HB or 2H) with a length of 2-3 mm accordingly; the pencil lead was broken several times under the same conditions while preserving the same fracture location and the length and orientation of the pencil lead in all the tests. Graph no.4 shows an example of the burst signal of the pencil test.

The test results are used to calculate the wave speed in this pipe material from the following equation

\[ V = \frac{2X_2 - X}{\Delta t} \]  

(2)

Where \( \Delta t \) is the time lag between the signals recorded at each sensor; which can be determined in a number of different ways, \( V \) is the sound waves velocity which depends on the pipe material, and \( X, X_2 \) are the same as used in the linear localization technique (equation -1).

The calculated wave velocity using equation (2) is 5150 m/s. This result ensures the accuracy of the sensors measurements because the wave velocity is close to the material properties of the used metallic pipe that is 5000 m/s for a pipe type Steel 347.

The results of the various tests using simulated sources on pipes as well as real sources focus on AE wave analysis. This analysis is based primarily on relatively simple statistical signal processing techniques. The main objective of the analysis was to understand the leakage effect on the subsea pipeline.

Graph no.5 shows an example of the continuous signal of AE records during the occurrence of leak.

The waveform in the time domain shows higher values in case of leak, but it still needs analysis to determine the differences in the recorded signals’ parameters.

During the analysis of results, the obtained measurements using different leakage hole diameters showed similar relationships to the acoustic emission parameters change, but with different values for each hole. Therefore, in the data analysis shown below, results for only one of the diameters are presented in each graph.

Figure 5. An example of continuous AE measurements during the occurrence of leak with 2 mm diameter.

In the time domain, Figure 6 illustrates the relationship between the energy values and the different leakage holes diameters. It shows a direct proportional increase in energy values with the increase of the hole diameter. The energy values due to leakage have a significant deviation from the reference values. This deviation ranges from 0.231 to 1.2.

Figure 6. Energy in (J) vs Leak diameter in (mm).
In figure 7, amplitudes generated due to the presence of a 4 mm diameter leakage hole dropped to lower amplitude values with the decrease in oil flow rates.

Figure 7. The relation between Amplitude value (Hz) and Oil flow rates.

Moreover, from figure 8, the counts number of a 4 mm diameter leakage hole decrease with the reduction of the oil flow rate. Nevertheless, the decrease rate in the counts number is lower than the amplitude values decrease as noticed from both figures 7 and 8.

Figure 8. The relation between Counts number and Oil flowrates.

In the frequency domain, Figure 9 demonstrates that average frequency values increase with time. However, these values decrease with the increase of the oil flow rates during the same time span, which introduces a better understanding of the relationship between oil flow rates and AE signal measurements parameters.

Figure 9. Change of average frequency values (Hz) with various oil flowrates in case of 3mm leakage hole diameter.

For the different holes, the increase of the leak hole diameter causes an increase in the time difference between sensor 1 and sensor 2 records, which is related to the increase of Reynolds number (Re) at the leakage hole (orifice).

$$Re\ at\ the\ orifice = \left( \frac{\rho V D}{\mu} \right)$$

Where D is the diameter of the orifice, \( \rho \) is the oil density, and \( \mu \) is the oil dynamic viscosity.

It was also observed that the time difference recorded by the two sensors helps in detecting the leak location (ABEE, 2011). In Table 1, the results from the AE data measurements (500 records) are calculated for a sub-water pipe with a hole of 1 mm diameter to determine the average time difference and the exact location of leakage using equation (1).

Table 1. Leak Location detection using sensors’ time difference of 1 mm leak hole diameter.

<table>
<thead>
<tr>
<th>( \Delta t ) - 1 mm leak hole diameter</th>
<th>Average ( \Delta t )</th>
<th>Leak Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>cm</td>
<td></td>
</tr>
<tr>
<td>0.015746</td>
<td>41.161099</td>
<td></td>
</tr>
</tbody>
</table>

The time difference between the two sensors is very small (15.746 ms average) which indicates a high sensitivity of the AE technique and helps in increasing the accuracy of leakage positioning with an error percentage less than 5 %.

4 CONCLUSION

This paper compared between the signals generated due to several leakages and in the sound condition. Also, it discussed the methods of acoustic measurements analysis of tested data that were extracted from time and frequency domains. Furthermore, pipeline leakage detection and localization systems were designed and established to simulate field transmission pipelines. The leak’s location formula was applied to detect the leak location.

The main findings include:

Several acoustic leakage signals were compared in time and frequency domains to examine the wave characteristics; waveform shape, counts, amplitude, energy, and average frequency. All these characteristics could be studied to get the mean values, and then compare these values to carry out an adequate analysis.

Through the analysis of these characteristics, the leakage signal could be distinguished. The pipe without any holes showed approximately equal signal parameter values. However, in the presence of
leakage influence on the AE recorded parameters, different values were noticed.

Most of the acoustic signals for the leakage are in the range of 0 to 200 Hz. The frequency spectrum of these signals could be used as another characteristic for leak detection.

The leakage location formula was applied to indicate the leak hole location. Errors in detecting the leak location were relatively low; the lowest calculated error value was 3.15%. Therefore, the sensitivity and leakage location accuracy are precise.

According to the experiments' results, the acoustic emission method proved high sensitivity for leakage detection and better accuracy in leakage location detection for subsea oil pipelines.

5 REFERENCES


