

Evaluation of Acoustic Emission Inspection of Oil Tank Floor via Tank Bottom Plates Thickness Measurement

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Abstract: This paper deals with an inspection of defects including corrosion and leakage by Acoustic Emission (AE) in an oil tank floor. 5 AE sensors have been attached to an oil tank and the sensors were calibrated by pencil lead break test. The emissions have been recorded within an oil tank. The oil tank was not emptied and had an amount of oil for the test unlike other test methods like magnetic flux leakage, eddy current or ultrasonic. The test method and formulas of AE investigation and AE source location are presented in detail. The result of AE test in the studied oil tank verifies the presence of corrosion in some areas of the tank floor. After AE test, the tank was emptied and inspected using ultrasonic thickness meter. The result of thickness measurement reconciles in an acceptable manner with AE test.

Keywords: Oil Tank Floor, Acoustic Emission, Defect

1. Introduction

Since 1950 AE is presented as a passive non-destructive test in various industries including oil industry. Due to the importance of safety in petroleum industry AE has been used to inspect the oil facilities such as tanks and pipes. Oil tank floor monitoring is more difficult than other parts of a tank since it is not accessible from outside. Moreover, they are covered with sludge and dust. AE provides an advanced method to inspect the floor of a tank while filled with oil products and enables tank owners to monitor tank condition without taking it out of service [1-3].

Generally, acoustic emission is an elastic wave caused by an abrupt release of energy within a substance. This energy would arise

from corrosion, crack growth or leakage in the material. As illustrated in Fig. 1 an AE wave has several features such as amplitude, duration, rise time, energy envelope and AE counts [4, 5]. These features are used to identify source location of an AE signal. They would also determine the extent of degradation of the bottom plates of an above ground oil storage tank [6]. For example it could be a positive proportional relationship between corrosion rate and AE activity [7]. Furthermore AE frequency and waveform would determine defect type. As a case in point while high frequency signals are arisen from slag inclusions and porosity specimens low frequency signals are generated from the growing cracks. In addition, porosity would

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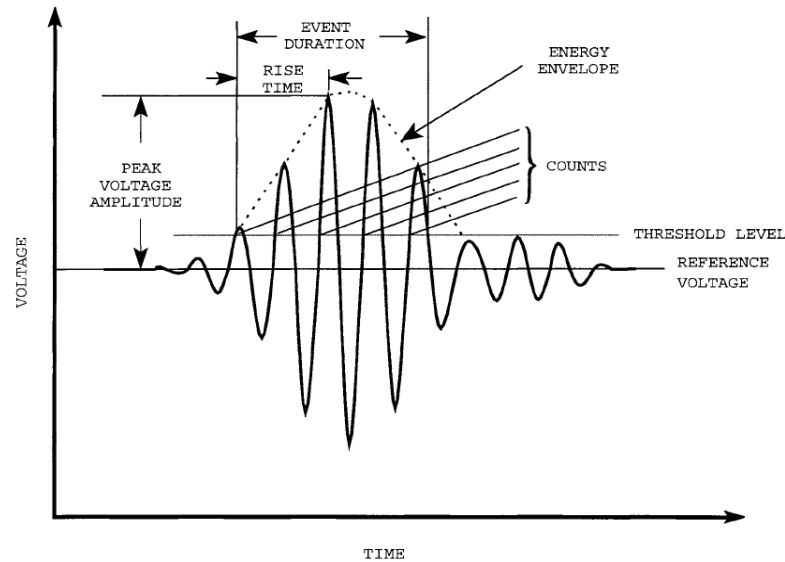


Fig. 1. Characteristics of an AE signal [6].

produce continuous type signals but slag inclusions indicate burst type of waveforms [8].

In order to AE inspection, AE sensors should be installed on the outside surface of the tank wall approximately 0.5 to 2 meters from the knuckle. This distance assures that sensors are high enough from silt layer of the tank and AE signals propagate through the oil product liquid [2, 9]. Adjacent sensors could be mounted approximately in a distance of 6 m along the circumference of the tank wall. However, this distance should not be exceeded 15 m [9, 10]. After receiving AE signals, they are magnified and analyzed in the data acquisition board and the process of source location of defects begins. This would be done by fast A/D convertors equipped for each channel [11].

2. Inspection procedure

This study is composed of two parts. First, AE used to inspect the floor condition of an oil tank. This test is performed while the tank is filled with oil product. At second part, the oil product is removed from the tank and ultrasonic is used to measure bottom plates

thickness as a tool to identify damage level and consequently assess AE test.

Studied oil tank was filled with product level of 70% which provides the required load pressure for AE. The oil product was gasoline. The tank diameter was 9.144 m by the height of 7.6 m and total capacity of 4000 BBLs. The roof of the tank was fixed. Tank plates were built from steel of grade C.

To meet the standard sensor arrangement, five AE sensors were mounted along the circumference of the tank wall by 6 m space at the level of 1.5 m above the tank bottom (Fig. 2). All sensors were 24 kHz resonant frequency with integral preamplifier and 10 kHz high pass filtering which matches well with the bottom plates defect (Fig. 3). The sensitivity of sensors was calibrated using pencil lead break. The calibration testing was carried out by threshold level of 70 dB. A MICRO-II SAMOS-32 from PAC (Physical Acoustic Corporation) which is a 32 channel acoustic emission system used to acquire the AE data which was equipped with a keyboard, a mouse and a monitor. AE data collection was performed with a threshold level of 40 dB.

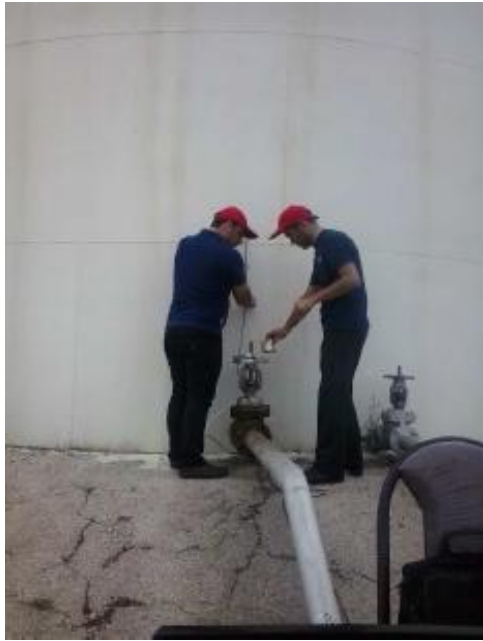


Fig. 2. AE sensor installation (TETA Co.).



Fig. 3. Installed AE sensors (KRN Services Inc.).

3. AE source location method

Fig. 4 depicts the tank schematic with the installed sensors around it. According to this figure after an AE event, the distance of the source and the first receiver sensor would be defined d_1 , the second receiver sensor has the distance of d_2 and the third receiver sensor has the distance of d_3 . It should be noted that the first receiver sensor could be any sensors s_1 to s_5 . So it is possible to write a system of non-linear equations using Euclidian distance differences as Eqs. (1) and (2):

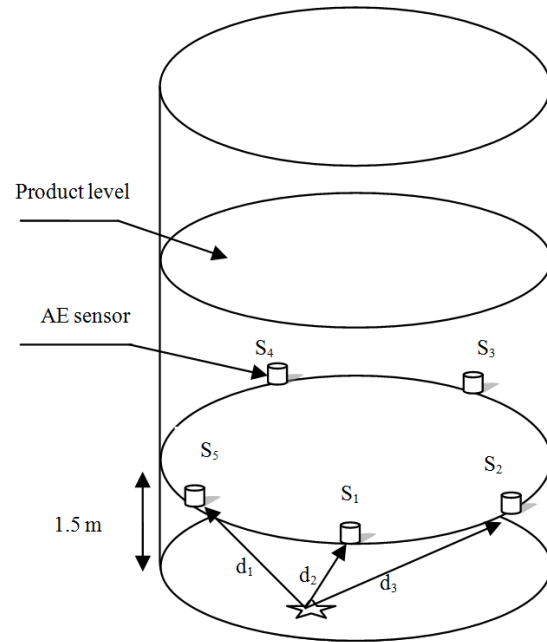


Fig. 4. Oil tank schematic with sensors s_1 to s_5

$$d_2 - d_1 = \sqrt{(x_2 - x_s)^2 + (y_2 - y_s)^2 + (1.5 - 0)^2} - \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2 + (1.5 - 0)^2} = c.(t_2 - t_1) \quad (1)$$

$$d_3 - d_1 = \sqrt{(x_3 - x_s)^2 + (y_3 - y_s)^2 + (1.5 - 0)^2} - \sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2 + (1.5 - 0)^2} = c.(t_3 - t_1) \quad (2)$$

In these equations $(x_i, y_i, 1.5)$ represents sensors location where $i = 1...5$. AE source location is defined as (x_s, y_s, z_s) that refers to the unknown part of the equations. The height difference of sensor position from floor is $(1.5 - 0)$. c is the velocity of AE waves which is known and can be defined as Eq. (3):

$$c = \sqrt{\frac{E}{\rho}} \quad (3)$$

where E is the Young's modulus of elasticity of the material and ρ is the density of the material [12]. Time differences

$(t_2 - t_1)$ and $(t_3 - t_1)$ are known from recorded AE data. Solving these two non-linear equations leads to AE source location (x_s, y_s) .

As solving these non-linear equations are not easy, in this research triangulation method used to find defective areas. Each AE signal should be detected by at least three sensors in this method. Fig. 5 illustrates an AE event received by three sensors in two dimensions. The distance between source location and the first receiving sensor is defined in Eq. (4) and Eq. (5):

$$d_{11} = \frac{D_1^2 - \sigma_1^2}{2(\sigma_1 + D_1 \cos(\theta - \theta_1))} \quad (4)$$

$$d_{12} = \frac{D_2^2 - \sigma_2^2}{2(\sigma_2 + D_2 \cos(\theta_3 - \theta))} \quad (5)$$

where

$$\sigma_1 = d_2 - d_1 = c.(t_2 - t_1) \quad (6)$$

and

$$\sigma_2 = d_3 - d_1 = c.(t_3 - t_1) \quad (7)$$

D_1 is the distance between first and

second sensors and D_2 is the distance between first and third sensors. θ , θ_1 and θ_3 are angles depicted in Fig. 5.

Utilizing Eqs. (4) and (5) two possible source locations are attained:

$$x_{s1} = x_1 + d_{11} \cos \theta \quad (8)$$

$$y_{s1} = y_1 + d_{11} \sin \theta$$

$$x_{s2} = x_1 + d_{12} \cos \theta \quad (9)$$

$$y_{s2} = y_1 + d_{12} \sin \theta$$

By varying θ it is possible to minimize these two found source locations and select the best one as estimated AE source location [13].

To proof Eq. (4) it is possible to write z_1 using θ and θ_1 with respect to Fig. 5 as follows:

$$z_1 = d_1 \sin(\theta - \theta_1) \quad (10)$$

$$\theta_1 = \tan^{-1} \frac{y_2 - y_1}{x_2 - x_1} \quad (11)$$

Using Pythagoras' theorem:

$$z_1^2 = d_2^2 - [D_1 - d_1 \cos(\theta - \theta_1)]^2 \quad (12)$$

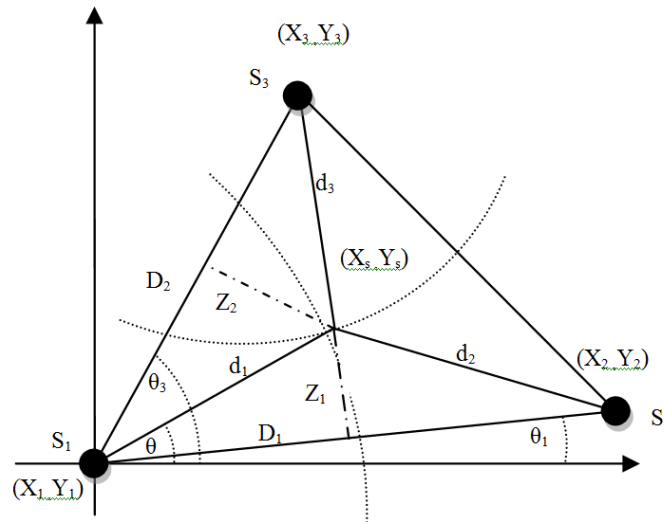


Fig. 5. AE source location in two dimensions using triangulation method [13].

Substituting Eq. (10) into Eq. (12) results:

$$d_1^2 \sin^2(\theta - \theta_1) = d_2^2 - [D_1 - d_1 \cos(\theta - \theta_1)]^2 \quad (13)$$

Expanding Eq. (13) yields:

$$d_1^2 = d_2^2 - D_1^2 + 2D_1 d_1 \cos(\theta - \theta_1) \quad (14)$$

Subtracting d_1 from Eq. (14) produces Eq. (15):

$$d_2^2 - d_1^2 = D_1^2 - 2D_1 d_1 \cos(\theta - \theta_1) \quad (15)$$

Adding $2d_1 d_2$ and using some algebraic relations in Eqs. (16) and (17) creates square form of the distance difference between d_1 and d_2 in Eqs. (18) and (19):

$$d_2^2 - d_1^2 + 2d_1 d_2 = D_1^2 - 2D_1 d_1 \cos(\theta - \theta_1) + 2d_1 d_2 \quad (16)$$

$$-2d_1^2 + 2d_1 d_2 = D_1^2 - 2D_1 d_1 \cos(\theta - \theta_1) + 2d_1 d_2 - d_2^2 - d_1^2 \quad (17)$$

$$-2d_1^2 + 2d_1 d_2 = D_1^2 - 2D_1 d_1 \cos(\theta - \theta_1) - (d_2 - d_1)^2 \quad (18)$$

$$2d_1 [d_2 - d_1 + D_1 \cos(\theta - \theta_1)] = D_1^2 - (d_2 - d_1)^2 \quad (19)$$

Substituting σ_1 from Eq. (6) into Eq. (19) yields:

$$d_{11} = \frac{D_1^2 - \sigma_1^2}{2(\sigma_1 + D_1 \cos(\theta - \theta_1))} \quad (20)$$

Which is equal to Eq. (4).

Fig. 6 illustrates the flow chart of source location program in MATLAB. The program utilizes Eq. (4) and Eq. (5) to find the distance of AE source and the first receiver sensor. Then by varying θ estimates the optimum source location from Eqs. (8) and (9).

4. Results and discussion

After pencil lead break test, the tank was tested using AE for 60 minutes. The result is depicted in Fig. 7.

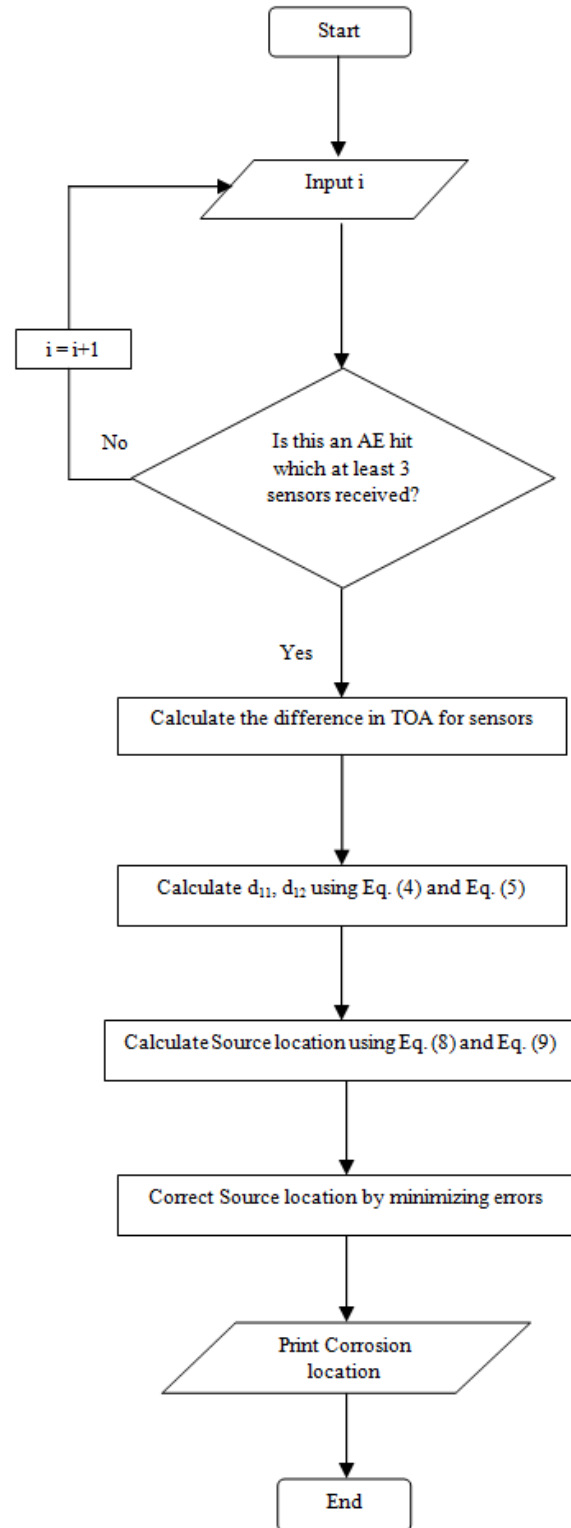


Fig. 6. AE source location flowchart.

In Fig.7, the big circle displays the tank floor. Small circles along the circumference

present sensors s_1 to s_5 . Black dots represent defects on the floor. From the figure it can be clearly seen that defective points are located mainly in a region between sensors s_4 and s_5 .

After AE test the tank floor was emptied, cleaned, and tested using an ultrasonic thickness meter. The result is depicted in Fig. 8. The thickness of the floor plates was 8.7 mm since the construction of the tank. As Fig. 8 shows most plates have a thickness of more than 7 mm and only 3 points have a thickness of less than 7 mm. It is also clear that these points are located in an area between sensors s_4 and s_5 . The lower thickness in this area

presents more corrosion and this is in accordance with Fig. 7. where most defects are located in the next region. Though there are points with slight corrosion in Fig. 8 which were not detected by AE test. Altogether it could be inferred that most active corroded points were found by AE.

Table 1 illustrates defect levels and necessary recommendations for tank floors. Since the low defect activity as depicted in Fig. 7, the tank floor condition is evaluated well based on Table 1 and no repair is required. However, it is recommended to be tested by AE again after three years.

Table 1. Classification of defects in tank floor [14]

Defect level	Grade	Required Action
very low	A	No repair
low	B	No repair
medium	C	Minor repair
High	D	Repair soon
Very high	E	Repair immediately

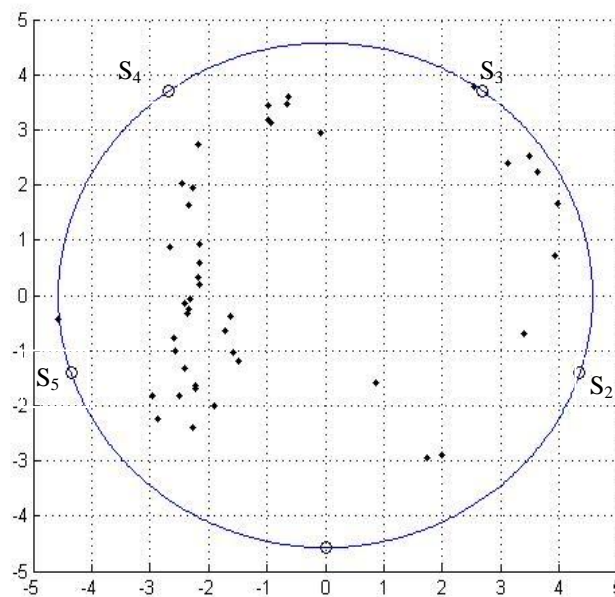


Fig. 7. AE source location of 60 minutes test.

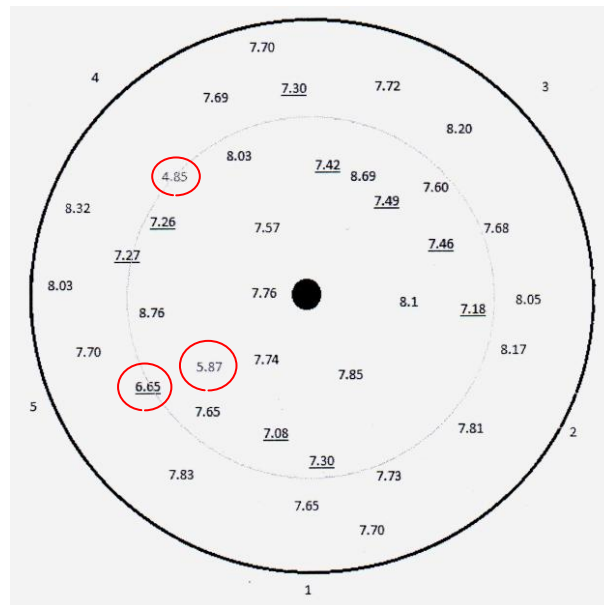


Fig. 8. Tank bottom thickness measurement.

5. Conclusions

AE is a passive non-destructive test which has been used for different structures including above ground storage tanks over the past decades. In this research the condition of an oil tank floor was inspected using AE and ultrasonic thickness tests. The outcome of both tests shows that there are a few corrosions in some areas of the tank floor chiefly in an area between sensors s_4 and s_5 . There is no significant leakage and the integrity of the bottom plates could be evaluated well. However, because of the low level degradation, the tank floor should be monitored after three years using AE test.

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