Heavy Oil Storage Tanks' Inspection -Using Acoustic Emission

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Abstract

This paper presents a new inspection method in Heavy Oil Storage Tanks'. Oil leaks may occur due to defects in tanks bottom, which pose a significant risk to the company's environmental, financial and reputation aspects. Traditional inspection technique is a long process that needs shutting down the plant, emptying the tank, cleaning, decontamination, and sandblasting, which is cost-time consuming and interrupts production operations. Recently, an advanced inspection technique called Acoustic Emission Testing (AET) has been employed by many companies as an alternative to the old traditional technique. AET can apply inspection and evaluation of tank internal condition from the external side, without the need of tank emptying and shutting down the plant. The theory of AET is based on sonic sensors that can detect sound signals generated by tiny leaks or defects in a tank while the tank is filled and in service. The sensors are attached externally to the tank external body and data can be acquired, then filtered, analyzed and evaluated to give valuable information about the tank's internal condition. In this case study, AET inspection was applied on a heavy oil storage tank in ISSRAN field-Egypt/ Eastern desert. The results yield a significant reduction in cost, time and overall risk.

Keywords
Above-ground storage tanks, Heavy oil, Acoustic emission testing, Advanced inspection and techniques.

1.Introduction
Scimitar Production Egypt Ltd. (SPEL) is an independent and private oil-producing company at the forefront of heavy oil production in Egypt. SPEL has the right of exploration and production in ISSRAN field in concession located in the Eastern Desert, 290 km southeast of Cairo. The field produces heavy oil (10-14 API) and was the first heavy oil development in Northern Africa stimulated with steam injection. Heavy oil production is a very challenging process that needs a specialized operation, especially steam injection in wells, making the production process more challenging. The heavy crude oil extraction process is based initially on steam injection applied to relatively shallow oil reservoirs, and contain crude oils that are very viscous. This method is called enhanced oil recovery (EOR) and is considered one of the main types of thermal stimulation of oil reservoirs.

Central processing facilities (CPFs) are significant assets in the field and are considered the primary production units. A recent oil leak in CPF1(storage tank) raised the red flag to activate the proactive inspection. CPF tanks inspection was deferred by three years which mandates immediate inspection to be applied, but the challenge here is applying the inspection and avoiding any production interruption at the same time, so the inspection should be done without shutting down the unit and the tanks let being operating in service.

The presented study shows the efficiency of using acoustic emission testing (AET) as an alternative to a tank traditional internal inspection. AET is an advanced inspection tool that can be used as a corrosion monitoring tool of a tank using well distributed acoustic sensors attached to a tank shell perimeter externally so it can be used when the tank is in service and eliminate the need for intrusive internal inspection (C.M. Nickolaus,1988). Using AET as an alternative to traditional inspection techniques is permitted by API and regulatory standards and can be employed as a risk-based assessment program under API std 653. The objective of this research will be reached by conducting an AET inspection on one primary tank in CPF2 (storage tank) as a demo trial to assure the effectiveness, quality, and sensitivity of testand data acquired.

The study results have shown that adopting the AET inspection technique has three significant benefits, including optimization of cost, time and risk. Comparison using project management tools such as Gantt chart showed significant benefits regarding time reductionand overall cost optimization while risk study using Bow-Tie approach showed eliminating multiple risksand overall risk optimization.

Oil storage tanks are designed and built according to API std 650. The Storage tank consists of three major components (Bottom, shell androof). The Tanks inspection andrepair measures are regulated by API std 653. Internal inspection activities are focused on the tank bottom because the bottom is the only tank part that cannot be accessed by external inspectionand the bottom is exposed to severe chemical corrosion resulting from the water settling by natural gravity in the tank's lowest part. Emulsion (Oil/ water) contains corrosive salts such as chloride and sulfide salts, which aggravate the bottom corrosion rates resulting in damage mechanisms such as local pitting and severe thickness loss. Inspection of the tank bottom is intended to assess the current bottom integrity and identify conditions that may lead to future loss of integrity.

Tank bottom internal inspection can be conducted by adopting traditional inspection techniques or advanced inspection techniques as an alternative. Traditional inspections require tank entry (confined space) to apply intrusive inspection for assessment; these techniques require shutdown andemptying of the tank. Such techniques include ultrasonic thickness measurements, dye penetrant test and CVI (close visual inspection) (API RP 575,2020). On the other side, advanced inspection techniques are based non-intrusive inspections without the need for tank entry (Van De Loo et al ,1988). They're based on In-service inspections performed while the tank is in operation, such as acoustic emission testing (AET), which may reveal important information without tank entry. With such data and information, Fitness for service (FFS) or Risk-Based Inspection (RBI) evaluations can be performed that can aid in maximizing the period of operation without taking the tank out of service. In addition, repair and replacement requirements can be planned and estimated in advance of taking the tank out of service to utilize downtime more effectively. These efforts can therefore contribute to overall plant availability by minimizing required downtime (Yuyama et al. 2007).

1.1Objectives

Perform the deferred inspection in Production unit CPF2-Storage Tank T 130A, by using AET, which is a new inspection technique used recently for evaluating the condition of above-ground storage tanks without the need for intrusive inspection. Moreover, a comparison study based on three aspects, including time, risk and cost, was applied to evaluate the efficiency of the new technique.

2.Literature Review

AET is a valuable tool for evaluating the condition of above-ground storage tanks. By determining the condition of the tank floor, tanks that require urgent attention can be identified and scheduled for maintenance, while a good tank can be left online and maintenance deferred. The cost of an acoustic emission inspection on a tank is only a fraction of the price of an internal inspection, so AET inspection allows money, time, and resources to be saved (Klinchaeam 2013). There are even environmental benefits by not emptying and cleaning tanks that do not require inspection or work to be carried out on them. There is also minimal disruption to plant operation, as tanks only must be taken offline for a short period of time. Its role in inspection condition-based maintenance management is as screening techniques for front-line input to risk-informed decision making. This correlation is enhanced using in-service tank maintenance history and AE (Acoustic Emission) grading as input to the decision-making on recommended follow-up actions and prioritizing tanks for allocation of maintenance resources (Martin 2012).

Acoustic emission tests are suited for obtaining the actual tank floor condition of flat-bottomed storage tanks regarding active corrosion and/or active leakage. One crucial part is to filter the raw data of the performed measurement subsequently in different steps. The location algorithm gives the most decisive filter criterion. It was shown that the raw data of the measurement contains from 3 to 9 % locatable AE data depending on the tank floor condition and the boundary conditions of the measurement (Lackner 2002).

3.Methods

This section presents inspection methods and procedures used in both traditional and advanced techniques.

3.1 Traditional Inspection Technique

Traditional inspections require tank entry to apply intrusive inspection for assessment, these techniques require shutdown andemptying the tank. Such techniques include ultrasonic thickness measurements, dye penetrant test andCVI (close visual inspection), as shown in figure 1. Before entering any tank, appropriate safety measures are necessary. Generally, such actions include isolation from any source of toxic or gas-generating fluids using blinds or disconnection/isolation, removal of hazardous liquids and gases, removal of gas-generating, pyrophoric, or toxic residues andassurance of an atmosphere that contains sufficient oxygen. Where applicable, OSHA and, or any locally applicable safety agency regulations for safe entry into confined spaces should be followed. A tank should be clean and free from surface residues, scale, and sediment to be properly inspected. Some oil tanks contain Naturally occurring radioactive materials (NORM) such as uranium, radium, and radon that are present in very low concentrations. These elements should be cleaned using special cleaning tools and procedures.

Taking ultrasonic thickness measurements at the most corroded areas is the common method of assessment. If extensive corrosion is evident, it is more effective to take several measurements on each plate or to scan the surface with a thickness-scanning device supplemented by ultrasonic prove-up. Numerous thickness measurements may be necessary for assessing thickness in accordance with API Std 653, Section 4 guidelines. Thickness measurements are taken on permanent points on bottom plates that are marked with permanent paint or marker to be measured frequently at different time intervals. These permanent locations are called CMLs (corrosion measurement locations). The quality of data obtained from the ultrasonic thickness technique is dependent on personnel, equipment and procedure.

After finishing the inspection and obtaining the thickness measurement data, the next step will be conducting analysis and calculations required to assess the thickness data. These analysis and calculations will yield valuable information about tank bottom condition and integrity, such as the corrosion rates, estimated remaining life, next inspection interval and the need for any repair, replacement of bottom plates (API RP 575,2020).

The Corrosion rate for thinning damage mechanisms is determined by the difference between two thickness readings divided by the time interval between the readings. The determination of corrosion rate may include thickness data collected at more than two different timings. Suitable use of short-term versus long-term corrosion rates shall be determined by the inspector. Short-term corrosion rates are typically determined by the two most recent thickness readings, whereas long-term rates use the most recent reading and one taken earlier in the life of the tank. These different rates help identify recent corrosion mechanisms from those acting over the long term.
The long-term (LT) corrosion rate shall be calculated from the following formulas (API Std 653,2020):
Long term corrosion rate (LT) = T initial- Tactual / Time between T initial and T actual (years)
The short-term (ST) corrosion rate shall be calculated from the following formula:
Short term corrosion rate (ST) = T previous- Tactual / Time between T previousand T actual (years)

Where:
T initial is the initial thickness at the same CML as T actual. It is either the first thickness measurement at this CML or the thickness at the start of a new corrosion rate environment, in in. (mm).
T actual is the actual thickness of a CML, in in. (mm), measured during the most recent inspection.
T previous is the previous thickness measured during the prior inspection. It is at the same location as T actual measured during a previous inspection, in in. (mm).
T min is the minimum design thickness required to maintain the mechanical integrity.

Tank bottom minimum remaining thickness value must meet the requirements of bottom plate minimum thickness Table.1. Suppose the calculated minimum bottom thicknesses (MRT), at the end of the in-service period of operation, are calculated to be less than the minimum bottom renewal thicknesses given in Table 1. In that case, the bottom shall be lined, repaired, replaced, or the interval to the next internal inspection shortened. The repair of internal pitting, when performed to extend the in-service period of operation, shall be by pit welding, overlay welding, or lap patching, followed by inspection and testing (Table 1).

Table 1: Bottom plate minimum thickness. (API Std 653,2020)

Minimum Bottom Plate Thickness at Next Inspection (in.)	Tank Bottom/ Foundation Design
0.1	Tank bottom/foundation design with no means for detection and containment of a bottom leak.
0.05	Tank bottom/foundation design with means to provide detection and containment of a bottom leak.
0.05	Applied tank bottom reinforced lining, > 0.05 in. thick, in accordance with API

	652.

The remaining life of a tank component (e.g., bottom, shell, or nozzle neck) due to thinning corrosion can be established using three key elements (the current thickness, the predicted or measured corrosion rate, and the minimum acceptable thickness T min). The current thickness is based on the minimum remaining thickness after any repairs. There can be different corrosion rates for the internal and external side (product-side and soil-side for bottoms). The minimum acceptable thickness is determined from the criteria established in API Std 653 for the various components. When the minimum acceptable thickness has been reached (further thinning can pose an integrity issue), action should be taken.

Remaining life general formula = Tactual-T min / Corrosion rate
As clarified, the traditional inspection approach is based on numerical analysis of thickness data which will yield quantitative results of minimum remaining thickness, corrosion rate and remaining life of tank bottom, so the traditional inspection approach is considered quantitative approach (Figure 1).

Figure 1. NDT Inspector performs thickness measurement on bottom plates and Dye penetrant test on bottom welds intersection (T welds).

3.2 Advanced Inspection Technique {Acoustic Emission Testing (AET)}

Acoustic emission testing is based on the principle that liquid leakage escaping through a defect in the tank bottom or shell produces a detectable sound. Tank bottom is stressed by oil head inside, while being tested, to stimulate the growth of discontinuities which emit acoustic emission (AE) signals from defects such as crack propagation or elastic and plastic deformation of the weak bottom points (ASTM E1930,2018). The higher the oil head, the more likely a leak will emit AE sound. Defect propagation in loaded solid materials such as tank metallic bottom results in a fast release of potential energy in the form of stress waves with frequencies typically between 50 kHz and 2 MHz, these waves propagate along with the structure for distances of several meters and are detected by piezoelectric sensors (ASTM E650,2015). Special analysis of detected AE waves is then performed to locate acoustic emission defect sources, identify defect type, evaluate the rate of defect propagation and its sensitivity to load/stress/operational changes (Van De Loo et al ,1988). The demonstration of this principle has shown that two types of sound are produced simultaneously (P. Tscheliesnig et al, 2000). One type is detectable in the tank bottom backfill material below the bottom; this impulsive sound extends beyond the audible frequency range and is the distinguishing characteristic signal (figure 2). The other continuous hissing sound is considered, along with other stray detectable sounds, to be noise (figure 3). For acoustic emission testing, noise is defined as any sound, continuous and, or intermittent, that is not a signal.

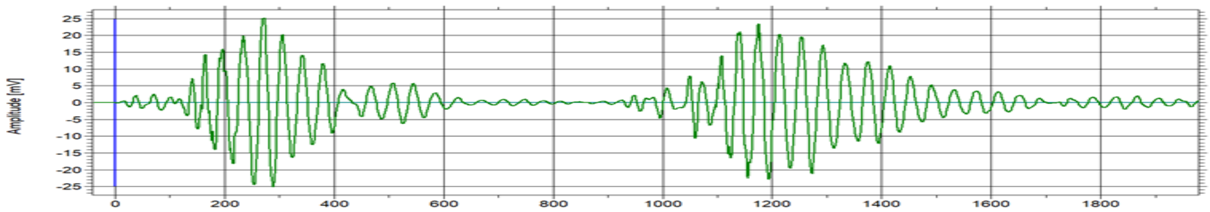

Figure 2. Example of a signal generated by a defect in the bottom plate

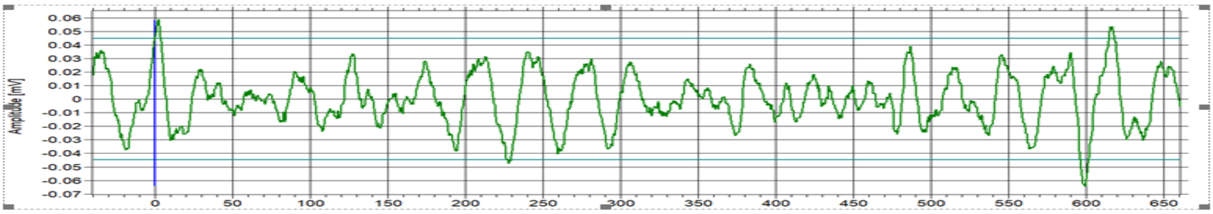

Figure 3. Example of a noise generated by the external source

4.Data Collection

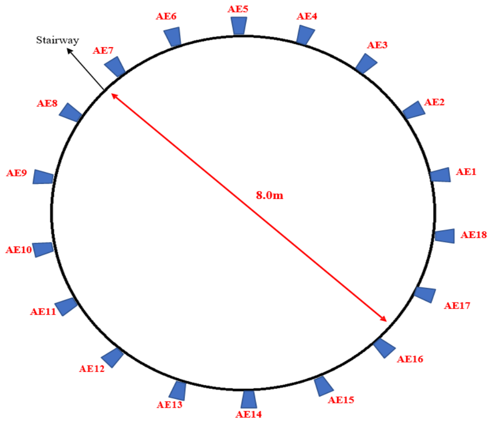

Figure 4. Top view of sensors arrangement attached to shell around tank perimeter

After The sensors are mounted around the tank, the data is acquired under static conditions for a period of 4 hours. Activities above the defined threshold voltage are considered as AE signals and later classified with a grading from ‘A’ to ‘E’ based upon various parameters (ASTM E1316,2014). The noise signals are filtered andexcluded from the acquired data and further analyzed (Figure 4). Locations of the detected AE signals on the tank floor, including corrosion, potential leakage activities, etc., are based on the first hit location analysis of signal hitting three sensors. The severity of these locations is assessed using various characteristics of the AE signal and Overall Corrosion Grading (OCG) shown in figure 5 / Table 2 and Potential Leakage Grading (PLG) shown in figure 6/Table3 are obtained.

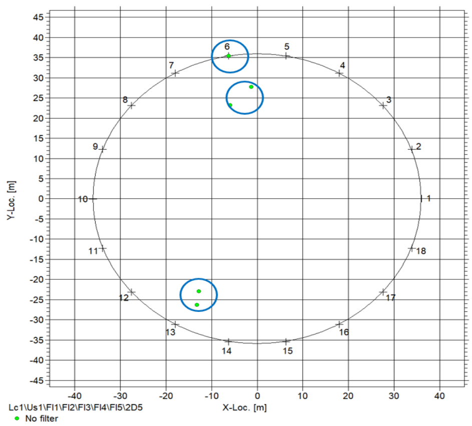

Figure 5. Represents corrosion activities in the tank bottom, which give an indication on OCG grading

Table 2. Overall Corrosion Grading (OCG) for Tank Bottom

Overall Corrosion Grading	Tank Bottom Condition

A	No Damage/Minor Damage
B	Intermediate Damage
C	Active Damage
D	Highly Active Damage
E	Highly Active and Severe Damage

Overall Corrosion Grading (OCG) for tank bottom is determined as "A". This indicates No Damage/Minor Damage to the tank bottom.

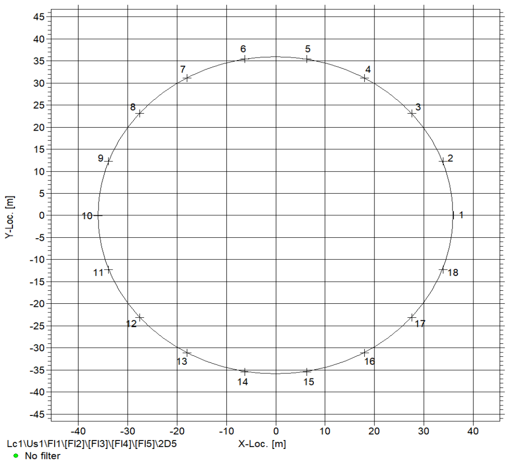

Figure 6. Represents Potential future leakage activities in the tank bottom, which give an indication on PLG grading.

Table 3. Potential Leakage Grading (PLG) of the Tank Bottom

Potential Leak Grading	Tank Bottom Activity indication
1	No Activity
2	Suspected Minor Activity
3	Moderate Activity
4	Sustained Activity
5	Major Activity

PLG (Potential Leakage Grading) for tank bottom is determined as "1". This indicates no suspected leakage activity in the tank bottom. Based on the above OCG of grade "A" and PLG of grade "1", the final RCG (Risk Category Grading) for tank bottom is determined as grade "I". shown in Table 4.
Inspection findings and recommendations from Table 3, Tables 4,, table 5 and table 6:

- A repeat acoustic emission inspection of the Tank should be carried out in 4 years unless an internal inspection of the tank is done within this period. Subsequent acoustic emission inspection/s will provide an accurate measure of AE activity growth in Tank bottom plate.
- Suspected weld defects around AE Sensor 13 (-13.05m(X), -24.58m(Y)) should be verified by close visual inspection in the nearest internal inspection.

Table 4. RCG (Risk Category Grading) Matrix for Tank Bottom

	OCG				
PLG	A	B	C	D	E
1	I	I	II	II	II
2	I	I	II	II	III
3	II	II	III	III	III

4	II	III	III	IV	IV
5	III	III	IV	V	V

Table 5. Risk Category Grading (RCG) results for Tank Bottom

Category grade	Next inspection (years)
I	4
II	2
III	1
IV	0.5
V	Require internal inspection.

Table 6. Source Localization indicating corrosion severity via grading

Activities	Location	Reference to AE Sensors
Acoustic Emission	(-13.05m(X), -24.58m(Y))	Near to AE Sensor
Acoustic Emission	(-3.65m(X), 25.5m(Y))	At AE Sensor
Acoustic Emission events	(-6.29m(X), 35.44m(Y))	Near to AE Sensor 6

As shown, the advanced AET inspection approach is based on corrosion grading and potential leakage grading analysis of acquired acoustic data, which will yield qualitative results of risk category grading of tank bottom, so the advanced AET inspection approach is considered a qualitative approach.

5.Results and Discussion

5.1 Numerical Results

A Comparison between the traditional and the advanced AET approaches was applied by defining the work breakdown structure activities then time and cost computing for both approaches applied on one tank. Results are shown in Tables 7 and Table 8.

Table 7. Work Breakdown Structure of Tank Inspection Project using Traditional Approach

S. N	Activity	Time (Days)	Cost (USD $)
1	Shutting down low priority wells and switching production to another Parallel CPF	2	0
2	Switching production to another parallel CPF	2	0
3	Tank Ventilation	3	100
4	Tank desludging and cleaning	7	500
5	Sandblasting of tank bottom andshell first course	3	1800
6	Scaffolding Erection	3	600
7	Conducting inspection using the traditional thickness gauge	3	500
8	Internal painting of bottom and shell first course	4	3200
9	Scaffolding Dismantle	2	400
Totals		29 Days	7100 $

Table 8. Work Breakdown Structure of Tank Inspection Project using Advanced AET Approach

S. N	Activity	Time (Days)	Cost (USD $)
1	Mobilizationand installing acoustic sensors around tank perimeter	1	0
2	Applying Acoustic emission inspection procedure	1	6500
3	Disassembly of sensors and demobilization	1	0
Totals		3 Days	6500 $

As shown in Gantt Chart figure 7, by adopting the AET advanced technique, we noticed significant time saving (only 3 days) compared with traditional techniques (29 days). Cost reduction about 600$ for one tank job, considering the cost of technical activities only. When considering the downtime of the CPF unit for 29 days, based on 71$ oil barrel price, The Total savings would be about (175000 $).

5.2 Graphical Results

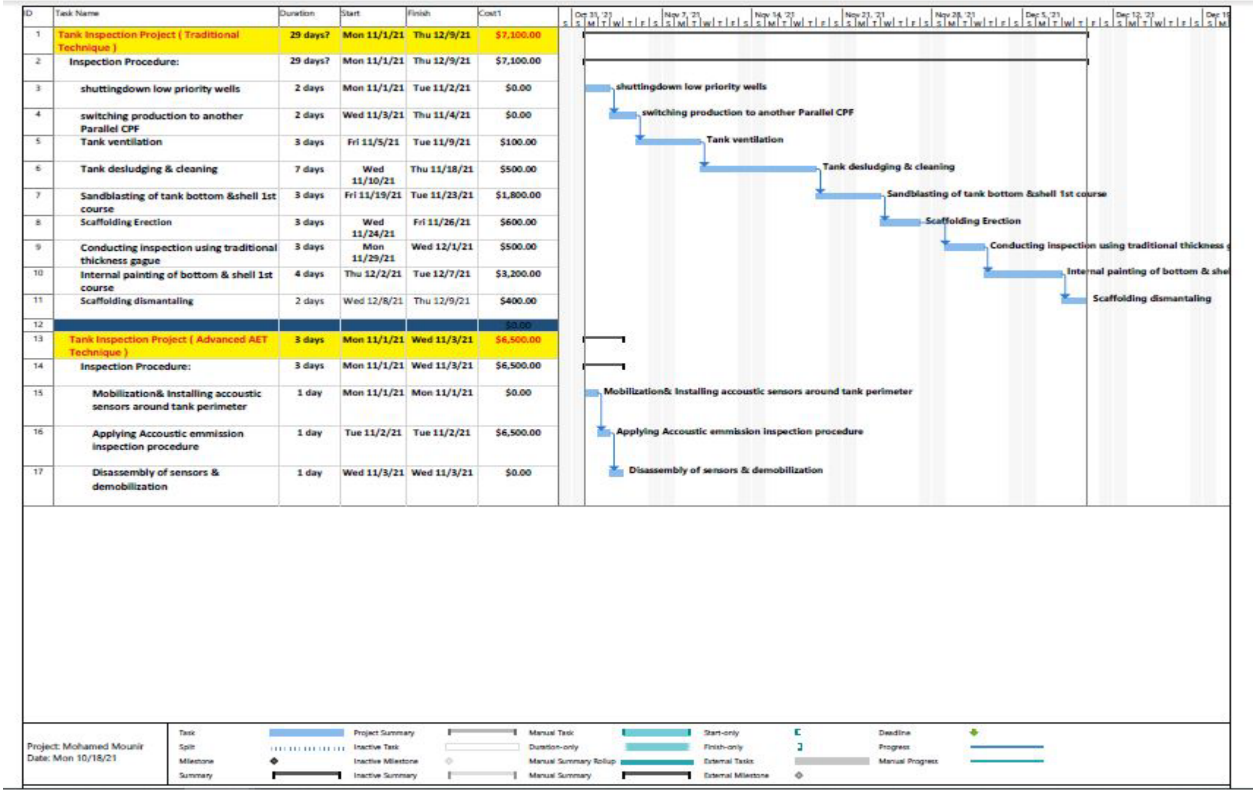

Figure 7. Gantt chart showing significant time and cost reduction in using AET technique compared with traditional technique.

One of the most essential benefits of advanced AET is avoiding the multiple risks associated with traditional technique. Working inside storage tanks is a highly hazardous work environment (Figure 7). Tanks may contain crude oil, liquid hydrocarbons, or other hazardous liquids. Potential hazards of tank confined space include oxygen deficiency, fire, explosion, and exposure to toxic substances such as NORM (Naturally occurring radioactive materials).

A Risk analysis study was applied using Bow-Tie Model shown in Figure 8, Figure 9 and Figure10. The multiple risks associated with the traditional inspection technique are complicated, need high precautions, readiness, competency and experience to deal with such potential significant events while, if compared to the risk of advanced AET inspection, AET has minimal risks and even cannot be visualized in the Bow-Tie model.

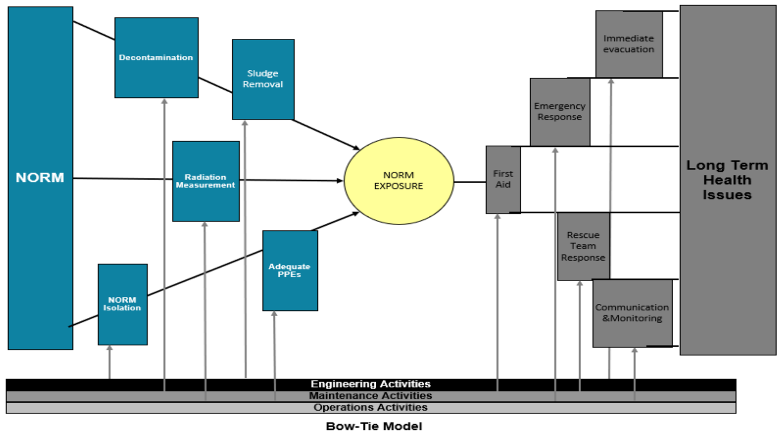

Figure 8. Bow-Tie model of NORM exposure risk.

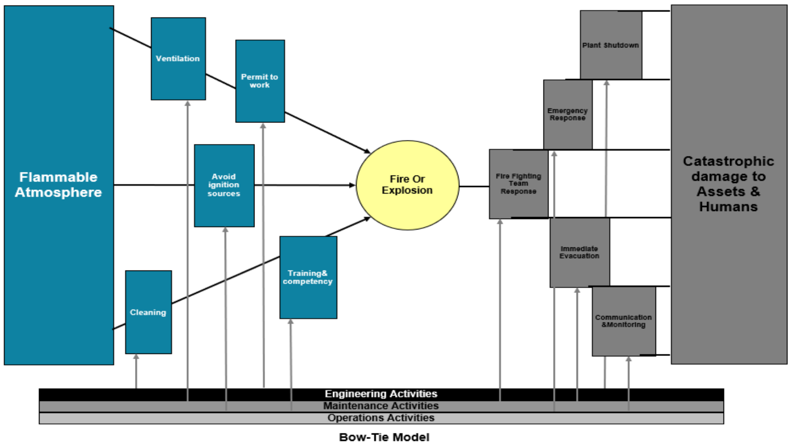

Figure 9. Bow-Tie model of fire or explosion risk.

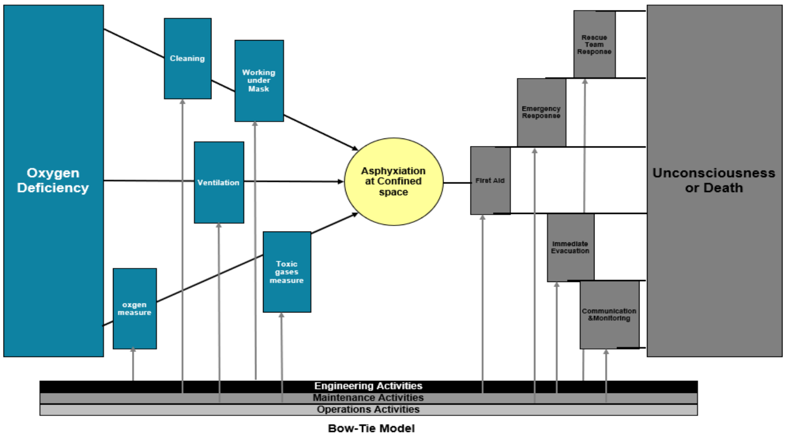

Figure 10. Bow-Tie model of Asphyxiation risk.

5.3 Proposed Improvement

Future research should focus on developing of modified sensors andAET hardware that can obtain quantitative data of the tank internals. With such improvement, the numerical data acquired can be translated into corrosion rate and further estimated remaining lifetime. Such improvement may eliminate the traditional technique forever because it is still the unique advantage that traditional technique delivers superior to the AET. Another modification may be applied to the current AET data analysis to gain quantitative results by using the degradation data analysis model to analyze the acquired corrosion data through a quantitative approach that will yield failure rates as an alternative to corrosion rates and failure time as an alternative to estimated lifetime.

5.4 Validation

All the data and results acquired from the AET approach applied on ISSARAN field were compared against historical data from another AET application on Abu-Rudies Field, South Sinai, Egypt. The results showed similar quality and sensitivity relevant to AE signals interpretation.

6.Conclusion

Storage tanks typically contain large volumes of valuable but potentially hazardous fluids. Inspection is a crucial element of the integrity management of storage tanks. The objective of the inspection is to provide information on the tank condition. Opening storage tanks for internal inspection is a lengthy and complex process, not only will the tank be unavailable during the internal inspection, but it must be drained and cleaned before entry is possible. There are also safety hazards associated with personnel entry for inspection. As such Advanced Inspection AET method offers an attractive alternative as they can be conducted while the tank is in-service and does not require tank entry. AET principle is based on sonic sensors that are attached to the tank external body perimeter. Those sensors can receive the sound signals generated from any defect or potential leak areas, then the data acquired can be processed, filtered and evaluated to give final inspection results shown as overall corrosion grading and potential leakage grading then a risk inspection matrix can be extracted from the two grading measures. The results obtained give information about tank internal condition, estimated remaining life, corrosion activityand recommendations for repair or replacement, or need for subsequent inspections.

A Case study was applied in ISSRAN field -CPF2 unit -Storage Tank T 130A. The AET inspection procedure was applied on this tank as a demo trial to assess the actual benefits from adopting this advanced technique and to check the quality of data and sensitivity of the overall procedure. Results were analyzed using advanced management tools, including PDCA (Plan, Do, Check, Act) cycle, WBS (Work Breakdown Structure), Gantt chart and Bow-Tie model. Results have shown a significant reduction in cost, time and overall risk.

Advanced Acoustic Emission Testing (AET) provides an effective superior alternative to the old traditional inspection techniques. The study showed significant benefits from adopting the AET technique as an inspection and maintenance planning tool for the above-ground oil storage tanks. These benefits include avoiding production interruption and multiple optimizations in time, cost and risk.

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