Oil and gas industry tanks Inspection, maintenance and repair as per international Engineering standard

فحص وصيانة وإصلاح خزانات النفط والغاز تبعاً لقوانين الهندسة العالمية

by

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Abstract

This dissertation is centered on inspection, maintenance and repair of oil and gas tanks. The tanks play a vital role of storing oil and gas products as they await transportation or further processing. These products are highly inflammable. They have to be well inspected, maintained and repaired to prevent cases of catastrophic failure. This paper explores these procedures, in relation to the American Petroleum Institute (API) 653 guidelines. The new technologies used in inspection have also been examined and their impacts on inspection, maintenance and repair projects. Primary data collected through questionnaires and interviews were used. The findings revealed that the new technologies used in oil and gas tank inspections include ultrasonic testing, robotic testing, and acoustic emission testing. The main advantage of using these technologies is that the storage tanks can be inspected without necessarily removing them from service. This has not only improved the efficiency of the processes, but also the safety of the inspection and maintenance personnel. The new technologies have also increased adherence to the API 653 guidelines because they have made it easier to conduct inspections on all the stipulated parts of the oil storage tanks. However, there are several areas of these guidelines that need to be improved. These areas include improving monitoring and audits, addressing the API 653 certification handled for the inspectors and putting in place stringent measures for non-adherence to the guidelines.

ملخص :

تتمحور هذه الأطروحة حول فحص وصيانة وإصلاح خزانات النفط والغاز الطبيعي. تلعب الخزانات دوراً مهماً في عملية تخزين منتجات النفط والغاز للنقل والتصدير وعمليات المعالجة. وبما أن منتجات النفط والغاز قابلة للاشتعال؛ يجب أن يتم فحص وصيانة الخزانات بعناية لتجنب حدوث الكوارث المحتملة. هذه الأطروحة توضح عمليات الفحص والصيانة بالاعتماد على تعليمات المعهد الأمريكي للبترول رقم 653. بالإضافة إلى ذلك، التقنيات الحديثة المستخدمة لعمليات الفحص تم إختبارها وتوضيح تأثيرها على مشاريع الفحص والصيانة والإصلاح. كما تم جمع المعلومات الأولية عن طريق الإستبيانات والمقابلات التي كشفت أن التقنيات المستخدمة في قطاع النفط والغاز هي كالآتي: الاختبارات فوق الصوتية والاختبار الآلي واختبار الانبعاثات الصوتية. الميزة الرئيسية لاستخدام هذه التقنيات هي أنه يمكن فحص الخزانات دون إزالتها مما يساهم في تحسين كفاءة الفحص و الحفاظ على سلامة موظفي الفحص والصيانة. كما عملت التقنيات الجديدة على زيادة التقيد بتعليمات المعهد الأمريكي للبترول رقم 653 لأنها سهلت عمل اجراءات فحص أجزاء خزانات النفط و الغاز. ولكن هناك مجال لتحسين تعليمات المعهد الأمريكي للبترول 653 التي تتعلق بمجالات المراقبة و التدقيق بالإشارة إلى الرخص الممنوحة للمدققين من قبل المعهد ووضع قوانين صارمة لعدم الالتزام بالإرشادات و التعليمات.

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1 Introduction

The oil and gas industry is one of the largest and most complex industries. It is an industry characterized by numerous operations including but not limited to oil production, refining and transportation. The products of the industry, which include diesel, gasoline, petroleum, and LPG gas are used in almost every other sector (Hassan 2013). Specifically, products such as diesel and petroleum are used for fueling motor vehicles, generators, farm machines, among many other applications. These uses clearly show that it is an invaluable industry in the growth of any economy (Hassan 2013).

However, to realize its potential, oil and gas companies should have the required infrastructure which ranges from oil drilling machinery, oil refining equipment, storage tanks and oil pipelines, among others (Inkpen and Moffett 2011). This equipment has to be inspected, maintained and repaired to ensure they are of the required integrity standards. This dissertation focuses on the inspection, maintenance and repair of oil and gas storage tanks (Inkpen and Moffett 2011).

Oil and gas products are highly flammable. A small incident such as minor spillages or leakages can result in massive financial losses and in some instances even deaths. In some cases, the affected company can run bankrupt or attract lawsuits, especially in cases where third parties are affected by the incident (Inkpen and Moffett 2011). One of the ways of preventing these incidents and which forms the basis of this thesis is ensuring that storage tanks are regularly inspected, maintained, and repaired. It is very unfortunate that oil and gas companies are keen on buying high quality storage tanks, but less concerned about having a robust inspection, maintenance and repair procedures (Hassan 2013).

To ease and standardize inspection, maintenance and repair procedures of oil and gas tanks, the American Petroleum Institute (API) has developed very stringent measures (Kumar 2012). These measures are supposed to be observed at all stages of oil storage, including during material selection of the storage tanks, design, actual construction and safe management of the operational storage tanks ('American Petroleum Institute' 2014). The development of the API guidelines was motivated by various incidents whose investigations pointed to poor inspection, maintenance and repair practices. Some of the incidents are described below:

Incidents that motivated the formulation of API standard 653

The American Petroleum Institute was compelled to develop standard 653 because of a series of incidents that rocked the oil and gas industry. The first incident occurred at a South Dakota School in 1987 (Cornell and Baker 2002). The incident involved oil leakage from an above-ground oil storage tank. The leakage led to the closure of the school because of the safety risk it posed to the students. The associated dangers compelled the congress to think of controlling above-ground storage tanks (Cornell and Baker 2002).

The second incident occurred in Pennsylvania on 2nd January, 1988. An above-ground tank containing approximately 95,000 barrels of oil failed. This led to a catastrophe whereby over one million gallons of oil were spilled into the Monongahela River. Millions of people were affected by the spill because water supplies were contaminated. This occurrence became an agenda of the congress as they sought to control the inspection, maintenance and repair of oil storage tanks (Cornell and Baker 2002).

The third incident occurred in 1988 where the California waterway was contaminated by approximately 100000 barrels of diesel. The source of the spillage was a floating roof drain of an oil storage tank. The investigation into this incident revealed that there were no repair standards that existed (Chang, James and Lin, Cheng-Chung 2006). This motivated the congress to develop standards to be followed by all players in the oil and gas industry. The above incidents resulted in the introduction of API STD 653 in 1991 that includes the guidelines for the inspection, maintenance and repair of oil storage tanks (Cornell and Baker 2002).

1.1 Overview of the API 653 standard

The constitution of the API standards was based on the suggestions of the most qualifies engineering professionals in the oil and gas industry. The goal of the standard is to examine and verify that a storage tank is fit for operation by looking at different parameters such as the integrity of the engineering structure and the corrosion rate of the materials used. This means the standard does not focus on measuring the likelihood of tank failure ('American Petroleum Institute' 2014).

There are a number of baseline requirements that must be followed by the owners of the oil storage tank as stipulated in the standard. One of the fundamental requirements is that the personnel involved in the inspection, maintenance and repair should be API 653 certified. This is a certification earned after rigorous tests and at least four years of experience. The requirement is meant to ensure that the personnel are well knowledgeable about oil storage tanks and the computations regarding structural integrity ('American Petroleum Institute' 2014).

The second basic provision of this standard is that inspections (in-service and out-of-service) have to be performed on the oil storage tanks. The decision to use either in-service or out-of service is determined by the characteristics of the storage tanks('American Petroleum Institute' 2014). When inspections are conducted when the tank is in-service, there are no interruptions because the tank is still being used as the inspection procedures are done. On the other hand, during out-of service inspections, the storage tank is not operational. This means the sooner the inspection process is completed the better because there would be no too much losses ('American Petroleum Institute' 2014).

The third primary requirement is performing routine external inspections. The owner of the tank has the discretion of hiring own personnel to perform these procedures. The routine involves thoroughly accessing the external status of the tank, appurtenances and the foundation. This is done to detect any form of shell distortions, leaks, corrosions and any signs of settlement ('American Petroleum Institute' 2014). Despite external inspections being informal, it is advisable to maintain inspection records. This is especially important in cases where any changes on the tank are observed. These records can aid in detecting patterns over a period of time which would signify the beginning of a problem. This in turn helps put in place corrective measures before a problem escalates to cause a catastrophe ('American Petroleum Institute' 2014).

1.2 Research Aim

Creswell (2014) defines a research aim as the overall goal to be achieved at the end of s study. The aim of this study is to analyse the suitability of various techniques used in the inspection, maintenance and repair of oil storage tanks in relation to API 653 standard. The study also seeks to identify how these techniques improve project management and the adjustments that need to be made to further enhance their effectiveness.

1.3 Research Objective

According to Kara (2012), research objectives refer to the sub-goals that a researcher intends to achieve towards the realization of the overall aim or goal. They serve as a reference point for the researcher hence ensuring the focus is on realizing the goal. The objectives of this study include:

- To determine the weaknesses of the new inspection Technologies.
- To determine how the API 653 standard guidelines and new technologies affects project management procedures during inspection, maintenance and repair of oil storage tanks.
- To recommend improvement measures for inspection, maintenance and repair of oil storage tanks.

1.4 Research Questions

Research questions enable a researcher to remain focused on achieving the research objectives. The following research questions guided this study:

- What are the main weaknesses of new inspection Technologies?
- In what ways does the API 653 standard guidelines affects project management procedures during inspection, maintenance and repair of oil storage tanks?
- What improvement measures for inspection, maintenance and repair of oil storage tanks should be taken to improve these procedures?

1.5 Problem Statement

Oil and gas companies invest heavily in infrastructure, including the storage tanks. Besides the high upfront costs incurred in purchasing these facilities, they have to undergo preventive inspection and maintenance procedures. It is unfortunate that even in the presence of these measures, oil and gas companies have continued losing these expensive assets following their failure. Depending on the magnitude, location and time of failure, the consequences can be devastating. For instance, most of the gas and oil products are highly inflammable. A leakage of such highly inflammable products can result in massive fires. Alternatively, in case of spills to water bodies, aquatic life may die besides negatively affecting other activities such as recreational activities, among others. This is notwithstanding the massive financial losses the companies incur ('American Petroleum Institute' 2014).

Unfortunately, the primary cause of these tank failures is skipped or poorly done inspection, maintenance and repair procedures. Skipped or poorly done maintenance procedures makes it difficult or impossible for tank owners to forecast failure and put in place appropriate preventive measures. Despite the introduction of API 653 guidelines, these cases of tank failures are not uncommon. This raises numerous questions about these guidelines. Is it their inefficiency that is resulting in these failures? Are oil and gas companies compliant with these guidelines? What technologies are oil and gas companies using during inspection, maintenance and repair? In what ways have they affected the management of inspection, maintenance and repair procedures? These are some of the concerns that have gone unresolved even under the heat of a significantly high number of oil tank failures.

1.6 Significance

Maintenance issues have been largely blamed for failure of oil storage tanks. It is unfortunate that even after the introduction of API 653 guidelines in 1991, maintenance-related failures of oil storage tanks are being experienced. This is evidenced by a number of failures which have occurred after the guidelines were introduced. One of the most recent cases occurred on 31st November, 2001 at Lafayett. A tank containing about 100,000 gallons of oil ignited, causing a very huge fire. However, the explosion did not cause any damages because the tank was located in a remote area.

The above incident, among others, shows that there is a need to re-evaluate how inspection, maintenance and repair projects can be better managed. This is very important in reducing the number of cases of oil tank explosions. These explosions have severe consequences to both the tank owner and to the environment. To the tank owner, a tank failure translates to the loss of an expensive asset. It also translates to loss of business because the tank is not in operation. On the other hand, the failures have devastating consequences to the environment. The Environmental Protection Authority (EPA) as a body mandated to protect the environment advocates for robust measures that would ensure oil spills and leakages are prevented. Some of the devastating consequences of oil spill include contamination of water bodies, and deaths of aquatic animals in cases onshore oil spill ('American Petroleum Institute' 2014).

The recommendations provided in this study will help prevent the occurrence of the above incidents. This is through the application of new inspection, maintenance and repair technologies. Additionally, it provides the measures that the personnel involved in these procedures need to observe to improve their project management capabilities.

1.7 Scope of the study

Scope refers to the "boundaries" or limits of a study (Creswell 2014). To ensure detailed investigation of a given area, the scope should not be too wide. In this regard, this study covers two main areas only. First, a detailed examination of oil and gas tank inspection, maintenance and repair procedures has been explored. This includes new technologies used in these procedures.

This is done in reference to the popular API 653 guidelines. Finally, the effects of new technologies and the API guidelines on project management have been explored.

1.8 Structure of the dissertation

This dissertation is structured into several chapters. The content of each of the chapters is provided below:

Chapter one: Introduction

This is an introductory chapter. It provides background information about oil tanks, the incidents that resulted in the formulation of API standard, 653, an overview of the standard, the aim, objectives, research questions and the scope. This means the chapter provides primary information on which the subsequent chapters are founded.

Chapter two: Literature Review

This chapter provides a detailed review of documented information about inspection, maintenance and repair of oil storage tanks. The chapter forms a basis for advanced research by identifying gaps in the available information.

Chapter three: Methodology

This chapter details the methods, techniques and procedures followed during the study. The choice of these methods, techniques and procedures has been justified.

Chapter four: Results and discussion

This chapter provides a detailed analysis of the results obtained following the application of the methodology described in the previous chapter. The qualitative and the quantitative results have been separately provided.

Chapter five: Discussion

The results are also discussed in detail in relation to the literature review chapter and the study objectives. This is intended to determine whether the findings confirm what is provided in the literature or they add new information to the existing pool.

Chapter five: Conclusion and recommendation

This chapter provides an overview of the main points in the dissertation. It details how the objectives have been met. It also provides recommendations about the ways in which inspection, maintenance and repair can be improved.

2 Literature Review

2.1 Chapter introduction

This chapter provides a comprehensive review of documented information about inspection, maintenance and repair. It also provides a review of project management practices in the engineering field. According to Kara (2012) literature review is very essential for any meaningful study. It provides a basis for the identification of gaps in the literature. Identification of gaps ensures the researcher does not duplicate the work of others. Rather, there is new information added to the existing pool of information. This chapter is divided into various sections including theoretical framework, the types of oil storage tanks, oil tank maintenance, conventional and modern inspection methods, corrosion monitoring and prevention, and research gaps.

2.2 Theoretical Framework

According to Creswell (2014), a theoretical framework provides the basis for examining a given topic. It is tries to expound on why a given research problem exists. The theoretical framework used in this study is based on the critical factors that influence success in engineering projects. It is worth-noting that since oil and gas companies are very large entities, inspection, maintenance, and repair projects are similarly large. This means they are subject to the same success and failure factors as other large projects. These factors include cost management, quality management, scope management, and time management (Sylvester and Rani 2011).

Cost refers to the total amount spent on a project. Cost estimates are done at the planning stage of a project. It is one of the metrics used in determining whether a project is successful or not. In case a project is not completed within the set costs, it cannot be deemed successful even in cases where all other success parameters are met (Sylvester and Rani 2011). Applying this analogy to oil tank inspection, maintenance and repair in the oil and gas industry, the tank owners would expect the project to be effectively completed at the minimum cost possible. This means they would expect their contractors to use the most advanced methods or technologies that would reduce the time and effort needed to complete the project. In this context, this would be applying the latest inspection, maintenance and repair technologies.

Another major consideration is time management. Time management is a crucial component of the overall project management exercise. A project that is not completed within the set timelines cannot be deemed to be successful even in cases where other success metrics have been met. Time has a close relationship with the cost management component. In case a project requires additional time, there are high chances that a proportionate increase in cost with be incurred (Sylvester and

Rani 2011). Similar to any other project in the oil and gas industry, tank inspection and maintenance projects are time bound. This is particularly the case when the tank has to be put out of service until the maintenance procedures are complete. It is based on this knowledge that contractors would opt to use technologies that would guarantee the project being completed within the stipulated timelines.

Quality management is another inevitable consideration in project management. Quality is a product of scope, time and cost. The implication of this is that for quality to be realized in any project, the scope has to be well managed and this should be done within the set timelines and cost (Sylvester and Rani 2011). During oil tank inspection and maintenance projects, quality work is very essential. This is because of the heavy repercussions of shoddy work emanating from tank failure. Quality work in this case is characterized by accurate examination of the structural integrity of the tank and implementation of the required measures (Sylvester and Rani 2011). Quality work is a major concern for contractors because it significantly influences their reputation. They will always strive to ensure they deliver work that is of unquestionable standards. This is by applying the most advanced technologies that have been tested and confirmed to provide desirable results (Sylvester and Rani 2011). In the case of inspection and maintenance of oil tanks, these technologies can include ultrasonic testing, acoustic emission testing, and robotic analysis, among others.

Finally, the scope is an aspect that needs to be carefully managed. Contractors will execute their work based on the scope of work. It is based on the scope that cost and time estimates are made (Sylvester and Rani 2011). Applying this in the context of this study, the scope can include performing a detailed assessment of the structural integrity of the tank using latest technologies and performing repairs as may be necessary.

Based on the descriptions of the success factors described above, it is evident that new inspection and maintenance technologies have a relationship with them all. The use of these technologies influences the time of completion, the quality and the cost of the project. This subsequently influences the overall project success. In the following section project management in the context of inspection, maintenance and repair has been provided in detail.

2.3 Project management

Maintenance procedure on oil tanks is considered to be any other form of projects. Similar to any other project, planning is essential. Most importantly, it is recommended that to observe safety precautions. There are several safety considerations which need to be made. Coordination is one of the critical considerations (Yuan and Ting 2017). Ideally, it is recommended that the maintenance personnel should undertake comprehensive planning prior to starting the maintenance procedures. The planning sessions should focus on areas such as probable risks and the procedures to be followed during the entire exercise (Yuan and Ting 2017).

The second consideration is the skill and professionalism of the personnel undertaking the exercise. According to the provisions of API standard 653, maintenance procedures should be undertaken by API certified professionals. Therefore, to enhance safety during the maintenance procedures, it is advisable that trained personnel with experience in maintenance procedures should be involved (Yuan and Ting 2017).

The third consideration is the provision of personal protective equipment (PPE). Maintenance procedures for storage tanks should not be undertaken without the correct protective equipment. These equipment protects the maintenance personnel from any injuries in the process of performing the procedures. Besides these PPE, it is recommended that the maintenance personnel should be provided with safety equipment (Kashwani and Nielsen 2017). For instance, there should be calibrated oxygen and gas detectors. These are intended to alert the maintenance team of any oxygen deficiencies. There should also be emergency kits to handle any form of emergencies in case they arise. However, these requirements are more critical when traditional maintenance procedures are used (Kashwani and Nielsen 2017).

Adherence to safety procedures is another critical requirement for all oil tank maintenance personnel. The API standard 653 has safety procedures that should be observed when undertaking maintenance procedures. These procedures are intended to ensure safety during inspection, maintenance and repair of storage tanks which are of different types (Kashwani and Nielsen 2017). The section below details the different types of tanks in the oil and gas industry.

2.4 Types of Oil Storage Tanks

There are various types of oil storage tanks that players in the oil and gas industry can choose from. The choice of the storage tank is informed by the intended use (Oil Care 2019). In most of the cases, above ground oil storage tanks are made of polyethylene or steel. These tanks come in different types, including single skinned tanks, double skinned or integrally bunded tanks (Oil Care 2019). A description of each of these types of tanks is provided below:

Single Skinned Oil storage tanks: These types of tanks are comprised of a single layer of plastic or steel. It is recommended that these tanks together with their pipework should be placed in a secondary containment system. This system is commonly known as the bund. These tanks are a great risk because in case of leaks, the product goes directly to the environment (Oil Care 2019). It is because of these risks that these tanks should only be used for above-the-ground storage. This is to enable physical monitoring and easy detection of any form of leaks. It is also recommended to perform frequent internal inspections to enable prompt identification of any wear arising from corrosion (Oil Care 2019).

Double skinned tanks: These tanks are comprised of two layers of plastic or steel. The space between the two layers is normally very small and thus ancillary equipment is placed outside the 2nd skin. The second skin also provides structural support to the tank. This considerably reduces the chances of failure while at the same eliminating the need for frequent maintenance procedures (Oil Care 2019). These tanks are particularly recommended for underground oil storage. This is because the space in-between the outer and the inner skins can be used in monitoring any leaks. This is unlike in single-skinned tanks where leaks can be directly absorbed by the ground without the owner noticing (Oil Care 2019).

Integrally bunded tanks: These tanks are comprised of both a primary container and an integral secondary containment. Any ancillary equipment is placed in the secondary containment. One of the major advantages of these types of tanks is that they are well designed to guarantee environmental protection (Oil Care 2019). In case of internal leaks, the stored product does not get to the surrounding environment. Considering the high safety measures imposed on these types of tanks, they are highly recommended for oil storage (Oil Care 2019).

In the following sections, detailed descriptions about the maintenance of the oil tanks described above have been provided.

2.5 Oil tank Maintenance

Maintenance of oil storage tanks should be a scheduled routine. It is a practice that ensures the storage tanks are always in good working condition and do not pose a safety risk to users or workers ('Steel Tank Institute' 2011). Maintenance of oil and gas tanks is especially very essential because of the catastrophic nature of oil and gas incidents which have been experienced in the past. The ease of maintenance is influenced by the type of oil storage tank under consideration ('Steel Tank Institute' 2011). Installation of a proper storage tank is the first measure to an easy maintenance experience. For instance, a double walled tank will require less maintenance than a single-walled tank. This is because the latter is more prone to failure compared to the former ('Steel Tank Institute' 2011).

It is worth-noting maintenance on oil storage tanks should be scheduled. This means the maintenance procedures have to be performed regardless of the condition of the tank. However, there are some cases when maintenance procedures can be performed prior to the scheduled time. One of such instances is when there are signs of oil drips. This might be an indication of a leak which might worsen if not promptly repaired ('Steel Tank Institute' 2011).

The second sign that would call for prompt maintenance procedures is the smell of fuel. This is an indication of leakage. However, it is not uncommon to have the smell of fuel when a tank is being refilled. This is because of the oil vapor that escapes during the process. Therefore, at such times, the smell may be ignored and maintenance procedures performed as scheduled ('Steel Tank Institute' 2011).

2.6 Oil Tank Inspection

Oil and gas tank inspection is an inevitable routine for oil and gas companies. It is a proactive measure aimed at checking the integrity of storage tanks. This in turn prevents the occurrence of major catastrophes that follow unfortunate incidents such as oil and gas leakages and bursts. While this has been observed by most of the oil and gas companies, the time taken in the exercise has resulted in financial losses (Papasalouros et al 2011). This is because the storage tanks are put out of service until the exercise is completed. Fortunately, technological advances have not only reduced the time taken during inspection, but also the exercise can be done while the tanks are still in use. Improved ultrasonic (UT) inspection techniques are convenient and effective for storage tank inspection. The methods are capable of monitoring and assessing the integrity of the tank without necessarily removing the tanks from service. This means there is no loss of productivity when these methods are used (Papasalouros et al 2011).

The UT methods basically work by collecting large quantities of UT data and subjecting it to intensive analysis using the readily available data analysis tools. This analysis gives a detailed report about the integrity of the tanks. However, these methods are applicable to the aboveground storage tank (AST) floors (Papasalouros et al 2011).

Electronic advances experienced in the past one decade have greatly enhances floor inspection for the aboveground storage tanks (Schempf et al 2005). The in-service robotic technology used in these tanks has not only improved inspection and cleaning capabilities, but it has also considerably improved operational efficiency. It is estimated that over 2000 in-service robotic inspections were done by 2009. This means by 2020, the number will have tripled (Raisutis et al 2017).

It is important to note that some tanks may need out-of-service inspections, despite the robotic technology being capable of performing in-service inspections. The decision to perform either in-service or out-of-service inspections is determined by various factors, including their age, inspection history and their condition. In cases where these factors are not favorable, it is advisable to put the tanks out-of-service before performing the inspections (Schempf et al 2005). However, it is anticipated that given the difficulties experienced in removing a tank from full service, the robotic inspection technology, which is compliant with the API standard 653 provisions will be extensively used in the near future (Schempf et al 2005). The following section details why oil tank inspection procedures are very important to every oil and Gas Company and individual oil tank owners.

2.6.1 Reasons for Oil tank Inspection

Tank inspection is a proactive measure undertaken by players in the oil and gas sector. There are various reasons that inform frequent oil tank inspections. The first reason is to reduce the probability of a catastrophic tank failure (De Simini and Raymond 2010). Inspections are meant to ensure that the condition of the storage tank is closely monitored. It is through this monitoring that it is possible for inspectors to notice any conditions that can result in catastrophic tank failure. An example is corrosion which weakens the tank over time, hence increasing the chances of a catastrophic failure (De Simini and Raymond 2010).

The second reason for conducting the inspection is to identify problems and perform the necessary repairs before any significant amount of oil is lost. In most cases, oil is stored in underground tanks (De Simini and Raymond 2010). This means cracks or holes in the tanks as a result of corrosion can lead to loss of fuel to the ground. This would result in great financial losses if this occurs for a long period of time without detection. It is therefore advisable to conduct such inspections to ensure that the integrity of the tank is intact and thus not prone to such losses (De Simini and Raymond 2010).

Another important reason for inspections is that they are cost-saving. This is because they enable tank owners to detect problems when they are still at their early stage. At this time, the repairs needed are small, easy to perform and less costly to remedy. Additionally, since the repairs are minimal, the tank only requires to be put out of service for a very short duration of time ('Health and Safety Executive' 2009). This is unlike when the problems are detected when it is too late. In such cases, major repairs which are usually too expensive may be required. The tank would also be put out of service for a very long duration of time. This would translate to massive financial losses in terms of the expenses incurred during the actual repair and loss of productive time for the period the tank would be out of service ('Health and Safety Executive' 2009). The following sections detail the conventional and the modern oil tank inspection methods.

2.6.2 Conventional oil and gas tank inspection procedures

Conventional tank inspection methods refer to the traditional methods used by oil and gas companies in monitoring the conditions of their oil and gas tanks. A major drawback with these methods is that the tank has to be completely put out of service before the inspection process commences (Judkins and Palacios 2009). The method entails a number of steps. The first step involves draining the tanks of all oil or gas. This is done through both fixed and temporary lines. This removes up to 99 percent of the oil volume. The remaining small quantities are removed using water, diesel diluents and squeegees (Judkins and Palacios 2009). After this has been done, oil vapour has to be removed because it is equally dangerous as the product itself. To remove the vapor, vapour-recovery burning tools/ equipment are used. After the tank is confirmed to be free of vapour, floor preparation is done. A common method used in floor preparation is sand blasting (Judkins and Palacios 2009).

There are various methods which can be used in tank inspection after it is confirmed the tank is ready. The two notable methods include the ultrasound testing and the magnetic flux exclusion. After the inspection has been done, the personnel involved carry out the necessary repairs (Judkins and Palacios 2009). The tank man-ways have also to be resealed prior to returning the tank to normal service. This process can take between one and six months. The duration is influenced by the tank size, the contractor schedules, the product and the magnitude of the necessary repairs. This means that for large tanks that require extensive repairs, their use can be halted for a very long period of time, resulting in financial losses (Judkins and Palacios 2009).

2.6.3 Modern Oil storage Tank inspection methods

The conventional oil tank inspection method has numerous drawbacks. Some of the notable drawbacks include financial losses because of the extended period of time a tank is out of service, high personnel costs and extensive planning needs (Schempf et al 2005). These drawbacks have been addressed by modern inspection methods. These include:

2.6.3.1 Robotic inspections

This inspection method uses robots connect to a monitoring system. A robot descends to the bottom of the oil tank while the tank is still in service. The robot moves across the floor collecting high-density UT data. The robot maps all the locations on the tank floor where this data is collected. It is estimated that robots have a location accuracy of ±2 in ('General Electric' 2019). The robot has a pump that is mounted behind it. The work of the pump is to remove all sediment and water from the floor of the tank. Immersion transducers attached to the bottom of the robot record the UT thickness readings. These readings are used in detecting the presence of bottom-side or topside corrosion (‘General Electric’ 2019).

It is important to note that as per the API 653 guidelines, inspection should not only be conducted in the interior of storage tanks, but also on the external parts of the tank. It is therefore advisable for inspectors to perform a traditional external tank survey. The results of the internal inspection should be combined with those of the internal inspection in order to meet the API 653 provisions (Schempf et al 2005).

There are numerous advantages associated with using the robotic inspection approach. One of the advantages is that there are minimal project planning requirements. This is because the tank is still in use during the entire inspection duration. This means there are no scheduling difficulties because the normal processes are not interrupted. This also means minimal resources are required because the process is simpler compared to the traditional inspection methods (Schempf et al 2005).

Another notable advantage is that environmental risks are significantly reduced. Environmental sustainability is an aspect that has drawn a lot of interest by governments worldwide. Oil and gas companies are expected to be party to these efforts. Robot-based inspection is one way of achieving this because there is no vapor released to the environment (Schempf et al 2005). This is unlike the traditional approach where the inspectors may be required to transfer oil to other reservoirs before commencing the inspection process. It is during this process that vapor is released to the environment. Additionally, there is a high likelihood of spills which further pollutes the environment (Schempf et al 2005).

Safety is another notable advantage of using the robot-based inspections. The use of robots in inspections means that no human personnel get into the tanks. Getting into the tanks and preparing them for inspection is a safety risk. The personnel are at risks such as suffocation or inhaling the oil vapors. Therefore, using robots eliminates this safety concern and increases the overall safety posture of oil and gas companies (Schempf et al 2005).

Robot-based inspections also maximize the lifespan of the storage tanks. Unlike the traditional inspection methods which require intensive planning and scheduling, robot-based inspections allow for frequent inspections. This allows for well-informed maintenance procedures for these storage tanks. This does not only increase their reliability, but also their lifespan (Schempf et al 2005).

2.6.3.2 Magnetic flux exclusion

Besides the use of robot-based inspection methods, the magnetic flux exclusion (MFE) method is another method used in inspecting tank floors. It is estimated that this technique is used in inspecting over 95 percent of oil storage tanks. One of the advantages of this technique is that it can be used in inspecting both lined and unlined tanks. The technique basically uses electromagnets to fully saturate the bottom of the storage tanks with a magnetic field (Papasalouros et al 2011). A scanner with sensors is used in monitoring the floor plates. There are different types of sensors which can be used in this technique. Some common examples include the giant magneto impedance (GMI) sensors, the magnetostrictive devices, the Hall Effect sensors and the search coils. The presence of any form of corrosion changes the magnetic field pattern. The change is detected by the sensors and reflected in the final inspection report (Papasalouros et al 2011).

Despite the advantages associated with this method, it has a major drawback. The method cannot differentiate between corrosion emanating from the internal side from that emanating from the soil side. However, this problem is only significant for underground tanks. For the above the ground tanks, it is possible for inspectors to verify the origin of the corrosion through external inspections. These external inspections are only applicable to unlined storage tanks (Papasalouros et al 2011).

2.6.3.3 Acoustic Emission testing

According to Javadi et al (2013), testing the floor of oil storage tanks has been one of the most difficult tasks. This challenge is more pronounced in cases where inappropriate testing methods are used. The difficulty arises from the floor being inaccessible from the outside which makes conventional Non-destructive Testing (NDT) not usable. Additionally, the expenses that would be incurred opening the tank and preparing it for inspection are enormous which would financially overburden the tank owner ('Integrity Diagnostics Ltd' 2015). Fortunately, the acoustic emission monitoring has proved to be an efficient method for addressing all these challenges. The method entails the use of highly sensitive sensors attached to the walls of the tank. The sensors detect any traces of corrosion or leaks on the tanks under investigation. The condition of the floor is put into a grading scale containing grade A to E ('Integrity Diagnostics Ltd' 2015).

A grade A rating implies that no or very minor unsuitable conditions have been detected. As such no maintenance procedures are required. Grade B category implies that minor unsuitable conditions have been detected. Similar to grade A conditions, no maintenance procedures are required for conditions that fall under this grade. Grade C category implies that the conditions are at the intermediate level (‘Integrity Diagnostics Ltd’ 2015). It is highly recommended that tank owners should perform some maintenance procedures if the acoustic testing exercise gives this grade (grade C). Grade D shows that the floor is in a deplorable state and thus should be given high priority in the maintenance schedule. Not adhering to this recommendation poses a high risk of tank failure. The final rating is grade E which means the necessary maintenance procedures should be initiated immediately; else there is a very high risk of tank failure (‘Integrity Diagnostics Ltd’ 2015).

The above rating information should be used together with other inspection data to accurately inform the course of action. This is essential because apart from the floor, oil storage tanks have other parts that require maintenance as well (Nowak et al 2019). Performing maintenance procedures on one part at a time may be an expensive and a time consuming exercise. Therefore, by collectively monitoring all the parts of a storage tank, maintenance procedures can be performed at the same time and this would save both on time and the expenses that would be incurred (Nowak et al 2019).

2.6.3.3.1 Disadvantages of Acoustic emission testing

The usage of this inspection method is limited by several drawbacks. The method is not conclusive because it only provides qualitative results. This means the magnitude of damage of the tank is qualitatively given (Loo and Herrmann 2009). There are some instances when qualitative data would not be sufficient. For instance, inspectors may be interested in quantitative aspects such as the depth and size of wear resulting from corrosion. In such a case, other methods such as the ultrasonic testing have to be used (Loo and Herrmann 2009).

In most of the cases, acoustic testing is done in noisy service environment. This noise if not reduced can affect the acoustic signals which are very weak. This can in turn affect the reliability of the results provided. Fortunately, this drawback can be overcome by oil and gas companies and tank owners, ensuring that they perform the testing in a quiet environment (Loo and Herrmann 2009).

2.6.3.4 Ultrasonic Testing

The ultrasonic testing is one of the most commonly used non-destructive methods used in testing the condition of materials. As the name suggests, this is a technology that uses sound waves in testing the conditions of various parts of a material. The sound waves are transmitted through the target material to determine certain properties and identify any internal flaws (Raisutis et al 2017). It is a method that is widely used in oil and gas industry to inspect the condition of storage tanks. This is because of its ability to provide quantitative data such as the depth and the size of the identified flaws. This is a property that lacks in other testing methods such as acoustic emission testing (Raisutis et al 2017).

The working concept of ultrasonic testing is similar to that of the sonar. A pulse is generated by a transducer and travels through the target material until a change in density is encountered or experienced. The change in density can be caused by two conditions, including the pulse reaching the target material's back wall or the presence of a defect (Maelka & Kazys 2019). The presence of either of these conditions results in the reflection of the pulse back to the pulse generator. The time that elapses between the pulse generation and the arrival of the echo is used in computing the material thickness at that location. The presence of an imperfection or flaw is indicated by a difference between the expected and the computed values (Maelka & Kazys 2019).

The above method is used to test for the presence of corrosion in oil storage tanks. These tanks corrode from within. The corrosion is attributed to the presence of sludge. Interior rusting is very risky because it cannot be easily detected (Maelka & Kazys 2019). In most cases and in the absence of a suitable, corrosion is detected after a leakage occurs. The ultrasonic testing can be used to avoid this by testing multiple locations. The differences in the densities of the tested areas would be an indication of the presence of corrosion. Therefore, initiating maintenance procedures would be highly advisable (Maelka & Kazys 2019).

2.6.3.4.1 Disadvantages of Ultrasonic testing

Ultrasonic testing has been hailed as one of the most suitable methods of inspecting storage tanks. However, the method has two main drawbacks. The method requires highly skilled and experienced personnel (Maelka & Kazys 2019). This is evidenced by the complex steps of testing and the computations that need to be done. This is a drawback which has resulted in some tank owners opting for other testing methods, despite not being as comprehensive as the ultrasonic testing (Maelka & Kazys 2019).

Repairs of storage tanks are expensive activities. This means they have to be undertaken when it is actually necessary. Unfortunately, the ultrasonic waves can give misleading information which would result in costly unnecessary repairs. To avoid such occurrences, it is advisable to repeat the testing at least twice for confirmation purposes (Maelka & Kazys 2019).

In the section below, corrosion as a major cause of tank failure and which informs repairs in most of the cases has been detailed.

2.7 Corrosion

Corrosion prevention is one of the major reasons why oil storage tanks should be regularly maintained. There are different forms of corrosion that can occur in gas and oil storage tanks. These forms vary significantly and thus classified in different ways (Speight 2015).

In certain forms of corrosion, no visible degradation occurs. However, this form of corrosion can result in unexpected failure of the storage tank because of the changes in the tank construction material. The implication of this is that these forms of corrosion are as severe as those where degradation is physically visible (Speight 2015). The available forms of corrosion include:

2.7.1 Uniform or general corrosion

As the name stipulated uniform corrosion uniformly occurs on the surface of a material. This form of corrosion uniformly reduces the thickness of a metal surface significantly weakening it. This is a very risky occurrence in oil and storage tanks because the thinned materials may fail to withstand pressure from the stored product resulting in unexpected failure. Fortunately, this form of corrosion can be detected through physical inspection and the necessary preventive measures put in place (Nalli 2012).

2.7.2 Localized corrosion

This form of corrosion is more prevalent than the uniform or general form of corrosion. Localized corrosion is characterized by severe dissolution of a material at a particular location. There might be no corrosion on the rest of the surface. Alternatively, corrosion may be occurring at a slow rate. There are several theories used in explaining this occurrence. The first theory is that there might be variations or differences along the material surface in the corrosive environment. This means different surfaces may be exposed differently to the agents of corrosion (Nalli 2012). As an illustration, a storage tank may have some of its parts in contact with the ground. In such an instance, the parts in contact with the ground are more prone to intense corrosion when compared to the parts raised above the ground. In such a case, localized corrosion is likely to occur. The second reason for localized corrosion is the mechanical factors. Examples of mechanical factors include the presence of an oxide film in the metal or stress. The metal surfaces with these characteristics are more prone to localized corrosion in the affected places (Nalli 2012). Some of these types of localized corrosion are detailed below:

2.7.2.1 Stress corrosion cracking

This type of corrosion is relatively common because the conditions for its occurrence can be easily met. One of the conditions is that there must be a tensile stress. This can be applied, locked or residual stress. The second requirement is that the material should be susceptible to corrosion and with a suitable/favourable microstructure. The final requirement is an enabling environment. Enabling environment is this case is characterized by the presence of dissolved oxygen, favourable pH and temperature, and the presence of hydrogen sulfide (Nalli 2012).

2.7.2.2 Galvanic Corrosion

This form of corrosion when there is a contact between two dissimilar metals. In such cases, one of the metals will preferentially corrode to the other. To help determine how the two metals will corrode, electrochemical potentials between the two metals can be used. This is important because it can be used by the storage tank owners in determining the preventive measures to take in order to prevent this form of corrosion (Nalli 2012).

2.7.3 Corrosion Monitoring and protection

Corrosion is one of the major safety concerns in oil and gas storage tanks. To adequately address this issue, the owners of these structures should have in place robust systems for corrosion monitoring and protection. The monitoring and protection costs may run into several billion dollars depending on the number and the sizes of the tanks. However, this expense is justified owing to the severe consequences of a tank failure. Some of these consequences include injuries or deaths of workers and the loss in finances. There are two techniques that are commonly used in corrosion protection. These include passive protection and active protection (Lyublinski, Kuznetsov, Schultz and Vaks 2013).

In active protection, focus in usually on project engineering, material selection and the alteration of the material corrosion process. On the other hand, passive protection mainly involves the application of protection layers in order to isolate the tank material from a corrosive environment (Lyublinski, Kuznetsov, Schultz and Vaks 2013). Since the focus of this paper is on maintenance, passive protection will be discussed. This is because active corrosion protection is primarily done during the material manufacturing phase.

There are several requirements which have to be observed before the corrosion protection layers are applied. The first condition is ensuring the protective layer is free from any pores. The presence of pores makes the agents of corrosion such as oxygen and water to get to the base material (Lyublinski, Kuznetsov, Schultz and Vaks 2013). This results in the corrosion of the material which is undesirable. The second requirement is that the material should have adequate corrosion resistant properties. An example of a material that falls in this category is the stainless steel. This is a material that can adequately protect the tank from coring hence ensuring it remains in uninterrupted service for a very long period of time. However, it is important to note that the use of protective layers does not absolutely guarantee protection from corrosion. Rather, the surface has to be well prepared prior to applying the protective layers (Lyublinski, Kuznetsov, Schultz and Vaks 2013).

2.8 Coatings

Coating the tank surface is one of the most commonly used methods for isolating the surface from a corrosive environment. This effectively protects the surface from corrosion (Rose 2017). Coatings are of several types which are classified as metallic, inorganic, and organic. Each of these classes is detailed below.

2.8.1 Organic coatings

These coatings are characterized by the formation of a thin barrier or layer between the material and the corrosive environment. It is the most commonly used type of coating because it is cheaper than the metallic and inorganic coatings. Actually, it is estimated that in the USA, over 2 billion dollars are spent annually on organic coatings. The high spending might give a notion of these coatings being expensive. However, it is the high popularity of these coatings that collectively results in high spending (Zheng & Li, 2010).

Currently, there are several organic coatings that are in common use. These include varnishers, paints, polyamide, epoxy, and lacquers. When used on the surfaces of storage tanks, the material is sufficiently protected from the agent of corrosion. This subsequently prevents unexpected cases of tank failure and all the secondary consequences (Zheng & Li, 2010).

2.8.2 Metallic and inorganic coatings

These coatings provide a good barrier against the agents of corrosion. However, there are several drawbacks associated with these coatings. The first drawback is that the inorganic coatings are very brittle. This means in the event of breakages, the exposed parts are prone to localized corrosion (Zheng & Li, 2010).

The oil and gas storage tank owners can use various methods when applying metallic coatings. These include, but not limited to flame spraying, vapor deposition, electro deposition, hot dipping and cladding. The suitability of each of these methods is based on the severity of the corrosive environment (Zheng & Li, 2010).

2.9 Repair of Storage Tanks

The structural integrity of storage tanks is one of the core considerations for any tank owner. At some point, the structural integrity of a tank may be reduced to a level that it is not desirable for the intended purposes. In such a case, it is recommended that the tank should be repaired. The repairs can be done in several ways ('Steel Tank Institute' 2011).

The first approach is replacing the material needed to restore the structural integrity of the tank. Some of the parts that can be replaced include the bottom, the roof and the shell. The second approach is adding reinforcing places to the shell openings. This makes the opening less prone to failure and subsequently preventing the severe consequences of such failures or incidents. The third approach may involve repairing any identified flaws. Examples of flaws in storage tanks include tears and gouges. These can be repaired by first grinding the affected locations and then welding them ('Steel Tank Institute' 2011).

2.10 Research Gaps

According to Creswell (2014), one of the primary goals of the literature review is to identify gaps in the documented information. It is based on these gaps that a study adds value to the area under investigation. Based on the information provided in this chapter, there are two major research gaps that are evident. The information provided in this chapter primarily describes inspection, maintenance and repair technologies commonly used by oil and gas companies. There is no mention about how these technologies have affected oil and gas tanks inspection, maintenance and repair projects. This study addresses this gap by detailing the contributions of these new technologies to project management.

The second notable gap in this chapter is that there is no mention of the weaknesses or failures in the popular API 653 guidelines. The chapter fails to explain the reason the guidelines have failed to completely eliminate cases of oil and gas tank failures despite emphasizing on preventive approaches. This chapter addresses this gap by detailing the weaknesses and the amendments that can be made to these guidelines in order to enhance the outcomes of inspection, maintenance and repair procedures.

3 Methodology

3.1 Chapter Introduction

In this chapter, a detailed description of the methods applied in the study is provided. Creswell (2014) observes that the methods used in a study are very critical. They influence the reliability of findings. As such, it is highly recommended that all the methods, techniques and procedures used should be justifiable. In agreement with this statement, the methods used in this study have been adequately justified. The chapter is divided into several sections. These include the research design, data sources, data collection methods, reliability and validity, data analysis methods, ethical considerations, limitations and the data analysis procedures.

3.2 Research Design

A research design defines the plan or template used in a study. The mixed research design was applied in this study. This is an approach where both qualitative and quantitative research approaches are used. There are several benefits of each of these two approaches that justify their use. Kara (2012) argues that qualitative research is founded on the notion that the most reliable and meaningful data can only be obtained from firsthand experience. It is also an approach suitable for collection of data about the beliefs of a group of people. Based on these descriptions, the suitability of the qualitative approach arises from two main areas. First, this study partially involved correcting expert opinions in the oil and gas industry about the ways in which the API 653 guidelines and new technologies have affected project management. This data is non-numerical in nature and thus qualitative.

On the other hand, the responses were quantifiable. This means the researcher could assign a numerical figure to some of the responses. For instance, the frequencies of some of the responses were determined and this gave the study a quantitative facet.

3.3 Data collection

Data is the foundation of any research. The quality of the data collected has a direct influence on the reliability and significance of findings. As such, the most relevant data sources and data collection tools have to be used (Creswell 2008). Secondary and primary data sources were used. The secondary sources used included books, journal articles, conference proceedings and white papers. These sources provided vital information, including but not limited to the new methods/ technologies used in tank inspection, maintenance and repair, the popular API 653 guidelines and their effects on project management.

On the other hand, primary data was obtained from professionals in the oil and gas industry. These included inspection and maintenance engineers and project managers.

3.3.1 Data collection tools/ techniques

As described by Kara (2012) a data collection tool refers to the device, strategy or instrument used during data collection. There are numerous data collection tools or techniques, including but not limited to observations, focus groups, questionnaires, interviews, records and document reviews, case studies, and experiments. The decision to use any of these techniques is largely dependent on the nature of the study. Interviews and questionnaires were the most suitable primary data collection tools because of the reasons detailed below.

3.3.1.1 Questionnaire

In basic terms, a questionnaire is a set of questions presented to a respondent by a researcher for the purposes of data collection. The questionnaire can be in print form or administered online through popular survey platforms such as Surveymonkey.com (Shields, Patricia and Rangarjan 2013). The questionnaires used in this study were closed-ended as shown in appendix 1. According to Creswell (2014), closed-ended questionnaires have choices where a respondent is expected to choose from. The decision to use questionnaires was informed by several.

Questionnaires are simultaneously administered to all respondents. This makes it possible to collect data from a large number of respondents within a very short period of time (Shields, Patricia and Rangarjan 2013). This was a benefit that had to be leveraged in this study. The researcher needed to collect the opinions from a truly representative sample that could justify generalization of findings. Questionnaires served as the best tools because data was collected from a considerably large number of inspection and maintenance engineers, and project managers in the oil and gas industry.

Consistency in responses is another quality that the researcher intended to achieve. Consistency in responses is an indication of truthfulness and reliability of findings (Shields,_Patricia and Rangarjan 2013). Questionnaires are the appropriate tool to help realize consistency. This is because they are standardized. Standardization in this case means the same set of questions is presented to all the respondents. This can result in promoting uniformity in understanding and most probably resulting in similar or consistent responses.

Convenience is another attribute of questionnaires that informed their use in this study. The environment of answering questions considerably influences data reliability. It is recommended that respondents should fill questionnaires in a comfortable environment as opposed to an environment where they are under pressure. Questionnaires provide such an environment because the respondent can fill them at any time and from any place (Shields, Patricia and Rangarjan 2013).

Ease of analysis is another advantage of questionnaires that informed their use in this study. The closed-ended type of questions used can be easily quantified. This is a feature that makes such questions easily analyzable. This is unlike interviews where a researcher has to read through all the responses matching similar ones (Shields, Patricia and Rangarjan 2013). Therefore, the use of questionnaires helped save a considerable amount of time.

Finally, questionnaires are confidential in nature. According to Kara (2012), respondents in most of the cases prefer remaining anonymous. This encourages them to truthfully provide the requested information without the fear of victimization. This increases the reliability of findings.

Despite the several advantages of questions provided above, this tool is not devoid of several challenges. The respondents may decide not to respond to the questionnaire in entirety.

Alternatively, they may be uncomfortable responding to some of the questions and thus decide to skip them altogether (Shields, Patricia and Rangarjan 2013). Any of such actions can compromise the reliability of findings. To avoid or minimize the effects of such actions, a considerably high number of respondents were used. This was meant to ensure that even in cases where some of the respondents decided not to respond at all or skip some of the questions, there would be still sufficient data from which to make reliable findings.

Questionnaires are meant to be filled by only the respondents who have been screened and confirmed to meet the inclusion criteria. Unfortunately, the respondents may decide to use third parties to fill the questionnaires on their behalf because of their busy schedules. This is an action likely to compromise the reliability of findings. To minimize the likelihood of such eventualities, all the respondents were informed about the need to fill the questionnaires by themselves.

3.3.1.2 Interviews

An interview is a one-on-one conversation between a researcher (interviewer) and a respondent (interviewee) for data collection purposes (Kara 2012). Semi-structured interviews were used in this study. The interview questions are provided in appendix 2. The use of interviews was justified based on several reasons.

The response rate is an aspect of great concern in any study. A high response rate implies sufficient data is available for analysis. Interviews, unlike questionnaires, have a very high response rate (Kara 2012). This is because of the presence of the researcher who guides the respondents in answering all the questions.

Interviews also allow for probing. Probing is especially important in cases where responses are ambiguous or unclear (Kara 2012). Through probing, it was possible for the researcher to seek clarity through follow-up questions. This ensured that the exact opinions of the respondent were captured.

Despite the advantages of interviews provided above, two challenges of this tool had to be addressed. Interviews are time consuming in nature. This is because unlike questionnaires, the respondents cannot be simultaneously interviewed (Kara 2012). To address this drawback, only a few respondents were involved in the interviews. Specifically, only three respondents were interviewed and this ensured only a short period of time was spent.

Data collected through interviews is difficult to analyze. Interview responses are mainly unstructured in nature. This means the researcher has to read through all the responses grouping responses that appear similar (Creswell 2008). To address this challenge, sufficient time was allocated for data analysis. It was also a challenge that was addressed by only a few respondents: three interviewees.

3.4 Inclusion Criteria

Kara (2012) describes inclusion criteria as a set of conditions that potential respondents have to meet before being allowed participation. Inclusion criteria ensure that only the most suitable subjects are involved in the study. In this regard, the respondents were expected to meet several conditions.

Participation was on a voluntary basis. The respondents were expected to consent to participation without expecting any monetary gains. Voluntary participation was essential because it ensured only the most willing took part in the study. This significantly increased their chances of providing reliable data.

The second condition was that participation was restricted to professionals in the oil and gas industry and with an experience of not less than five years. This requirement ensured that the participants were highly knowledgeable in areas such as oil tank inspection, maintenance, repairs and project management.

3.5 Sampling method and sample size

A sampling method refers to the technique used by a researcher to select study subjects from a study population (Creswell 2008). In this study, population is comprised of the inspection and maintenance professionals in the oil and gas industry. There is a high number of these professionals and hence not all could take part in the study. According to Kara (2012) the sample should be representative of the population and should be comprised of the most qualified in the sector under investigation. To ensure that only the most qualified were involved, purposive sampling was used. This is a sampling strategy whereby the participants are selected based on their level of knowledge in a given area. Only experienced engineers in the inspection and maintenance of storage tanks were involved. The professionals were drawn from four companies, including Abraxas Petroleum Corp, Adams Resources & Energy Inc, Amplify Energy Corp, and Anadarko Petroleum Corp. A sample size of 23 professionals was used. Twenty of the respondents were engaged through filing of the questionnaires while the remaining three respondents were engaged through interviews.

3.6 Reliability and Validity

Reliability and validity are two essential elements of any study. It is the prerogative of researchers to ensure they have in place sufficient measures to safeguard the reliability and validity of findings (Creswell 2008). The section below details the measures adopted to guarantee reliability and validity of findings.

3.6.1 Reliability

Reliability refers to the extent to which the findings can be consistently reproduced if a study is repeated under similar conditions (Creswell 2008). Based on this definition, it is evident that reliability is a core component of any research study. Researchers have a duty to implement measures that would guarantee the reliability of findings. In this regard, there are several measures that were implemented to safeguard the reliability of findings.

The application of stringent inclusion criteria positively contributed to the realization of reliable findings. The criteria ensured that only the most qualified were allowed participation. This increased the likelihood of collecting truthful information. The means even if the study is to be repeated severally under the same conditions, the same results would be obtained.

The decision to conduct pre-testing of the questionnaires also helped uphold the reliability of findings. By pre-testing the questionnaires, ambiguities were eliminated. Ambiguity can result in differences in findings because a different set of data would be gathered with every repetition. By eliminating all ambiguities, there are very high chances that the same data would be collected if the study is to be repeated severally under the same conditions.

3.6.2 Validity

Validity is another important element of any meaningful study (Creswell 2008). Creswell (2014) defines validity as the degree to which a research instrument measures what it is supposed to measure. Interviews and questionnaires were used in this study. To ensure validity of these instruments, the researcher implemented several measures.

The involvement of experts in drafting the questionnaires and the interview questions was the primary approach that the researcher used to ensure validity of instruments. The experts based the question-formulation process on the aims and objectives of the study. This ensured that the tools captured information relevant in responding to the study aims and objectives.

The research environment significantly influences external validity. To ensure there was no negative influence, the researcher applied two main approaches. The first measure was giving the respondents sufficient time to respond to the questionnaires. This allowed the respondents to choose the environment and the time they deemed comfortable and convenient to them. This had a positive effect on their productivity with regard to responding to the questions.

3.7 Data Collection Procedure

Kara (2012) recommends a systematic or procedural data collection process. Systematic in this context implies that the procedure must be justifiable. They should not be an arbitrary set of stages. In this regard, the data collection procedure used in this study was characterized by several steps.

The first step was the identification of the oil and gas companies from where the respondents would be sourced. After the companies had been identified, the second step involved seeking permission from the top management about the intention of engaging some of their staff in the study. This was necessary to avoid cases where the employees would be stigmatized for participating without the approval of the top management.

The third stage was meeting the target employees and detailing them about the study. This was followed by purposive sampling, where the most suitable employees were identified. To fully confirm their participation, and information sheet and consent forms were emailed to the respondents. A sample question form sent to the respondents is provided in appendix 3. The information sheet contained detailed information about the study. After reading the information contained in the information sheet, the respondents were supposed to indicate their willingness to participate by signing the consent form.

The fourth stage was distributing the questionnaires. The questionnaires were emailed to all the respondents. The respondents were given a duration of three weeks to respond to the questions. This time was justified because engineers in the oil and gas industry have busy schedules. Therefore, allocating a short duration of time would put these professionals under pressure, hence compromising the accuracy of the data they provide.

Interviews were simultaneously administered with the questionnaires. This was very important because it helped reduce the amount of time spent in data collection. The respondents decided the convenient time for the interviews. The interviews were conducted over the phone and every session took approximately 30 minutes.

Following successful administration of the questionnaires and the interview questions, the researcher gathered the questionnaires and the interview responses and prepared them in readiness for the final process: data analysis.

3.7.1 Pre-testing Questionnaires and interview questions

Ambiguity is a feature that compromises understanding. This in turn compromises the reliability of findings. To avoid such a case, it is highly recommended that the questionnaires should be pre-tested (Creswell 2008). The questionnaires were pre-tested three weeks to the actual administration. The aim of pre-testing was to identify any ambiguities and make corrections accordingly. Five participants who had met the inclusion criteria were involved in the study. Following the exercise, minor cases of ambiguity were identified. The appropriate corrections were made.

The interview questions were also pre-tested using qualified personnel. This involved conducting mock interviews using the actual questions. This was an exercise that was intended to measure the understandability of the questions and make the necessary adjustments. Following these mock interviews, appropriate adjustments were made.

3.8 Limitations

Creswell (2014) describes limitations as the occurrences beyond the control of the researcher and which negatively affects the reliability of findings. Similar to any other study, several limitations were experienced in this study.

Information about inspection, maintenance and repair was scarce. The implication of this is that this is an area that is less explored. Most of the review done was based on the API 653 guidelines which lacked sufficient data about the area in study. This is an aspect that might have considerably affected the depth of the research.

The second limitation arose from the unavailability of some of the respondents at the scheduled time for interviews. The busy work schedules made some of the respondents to keep on postponing or changing their scheduled interview time. Additionally, the respondents demanded rushed interviews as they had other activities to attend to. This affected their concentration during the interviews. This is an aspect that I believe might have negatively affected the reliability of findings.

3.9 Ethical Considerations

Kara(2012) notes that ethical considerations are essential in studies involving human subjects. Human subjects were involved in this study. Therefore, adherence to ethical standards helped cultivate a cordial interaction with the respondents. It is also because of adhering to acceptable ethical standards that conflicts were avoided contributing to a successful incident-free study.

Informed consent is the first ethical consideration made in this study. In line with the requirements of informed consent, all the participants were comprehensively informed about what the study involved. This was done three weeks prior to the start of the study. This gave them sufficient time to decide whether they were willing to participate or not.

Confidentiality was also observed during the study. This was achieved in two main ways. First, the respondents were advised against including any personal details in the questionnaires. Personal details in this case include information such as the name, phone numbers or physical addresses. On the same note, the researchers did not record identifying information of any respondent. The reporting has also been done in a way that it is not possible to link the responses to the respondents.

The use of information for the intended purpose was another ethical consideration that was made in this study. The respondents were informed about the purpose of the study and the intended use of the information. This means using the information for any other purposes would be unethical. Therefore, the information was protected and strictly used for the intended use.

Finally, the researcher cited all information obtained from secondary sources. In this research, both primary and secondary sources were used. It is an ethical practice to acknowledge the work of others rather than presenting it as one's own work.

3.10 Data analysis

Creswell (2014) defines data analysis as the process of getting meaning from data. The quality of analysis influences the reliability of the conclusions. Qualitative and quantitative data analysis methods were used in this study. The use of these two data analysis methods was justified because of two main reasons. The first reason is that the responses collected through the questionnaires are quantifiable and this allows for quantitative data analysis methods to be used. On the other hand, the data collected through interviews was qualitative in nature. It involved collecting the opinions of the respondents pertaining to the problem under investigation. This justifies the application of qualitative data analysis methods.

The quantitative approach involved quantifying the responses into frequencies and percentages. The percentages were used in drawing graphs and thus effectively creating a visual presentation of data. Visual presentations help improve data interpretations because it improves data clarity.

Thematic analysis was used for qualitative analysis. According to Kara (2012) thematic analysis entails identifying data patterns or common themes. There are several reasons why a thematic analysis was justified in this study. One of the benefits is that thematic analysis is a highly flexible data analysis technique. This means the researcher can alter the analysis process as deemed fit.

The second advantage of this method is its simplicity. Thematic analysis is a simple data analysis method which can be used by even the less qualified researchers to make reliable findings. The researcher leveraged this benefit to make reliable findings.

Thematic analysis involved a number of steps. The first step was familiarizing with the data. Data was collected from different respondents. This means varying responses were obtained and especially for the interviews. It was therefore important for the researcher to read the responses to get an idea of what the responses contained. The second step was coding the data. This entails assigning special codes to the data based on relevance. The grouping of this data was done based on the objectives and the literature review. Finally, the identified themes were explained in relationship to the study objectives.

4 Results

4.1 Chapter Introduction

This chapter details the results obtained following the application of the methodology described in the previous chapter. The chapter is divided into two major sections. The quantitative section provides an analysis of quantitative data. The qualitative section presents an analysis of the qualitative data. Each of these sections is divided into a number of sub-sections.

4.2 Quantitative Analysis

4.2.1 Profile of respondents

The purposive sampling used in this study was meant to ensure that only the most knowledgeable and experienced respondents were involved. All the respondents were maintenance engineers with varying years of experience. The number of years of experience of the respondents is as shown in the graph below.

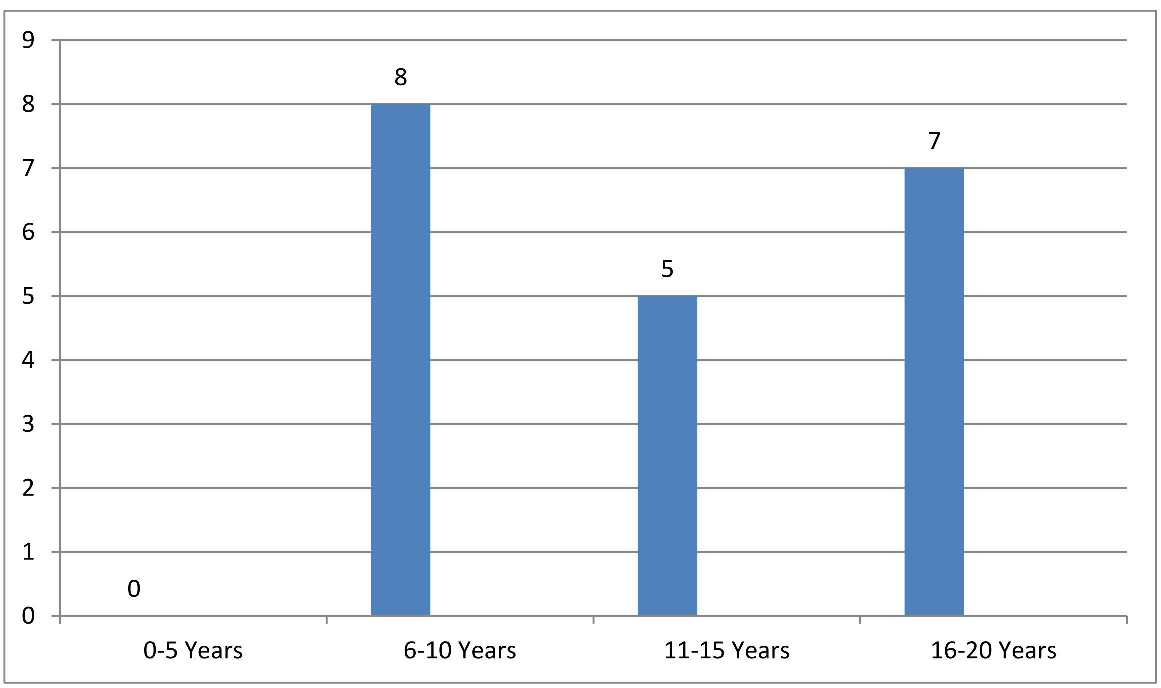

Figure 1: Years of experience

Based on the information shown in the graph below, all the respondents had at least five years of experience in maintenance work. Seven respondents had more than 15 years of experience, five had 10-15 years of experience, and the remaining eight respondents had 5-9 years of experience. This shows the respondents were adequately experienced to provide reliable responses.

4.2.2 Inspection and Maintenance of various parts

Oil and storage tanks are comprised of various parts. While all these parts are important for effective operation of the tank, some parts may require frequent inspection and maintenance procedures. This is because of their high susceptibility levels to the agents of failure. It is based on this argument that this question sought to determine the inspection and maintenance preferences accorded to different parts of oil and gas storage parts.

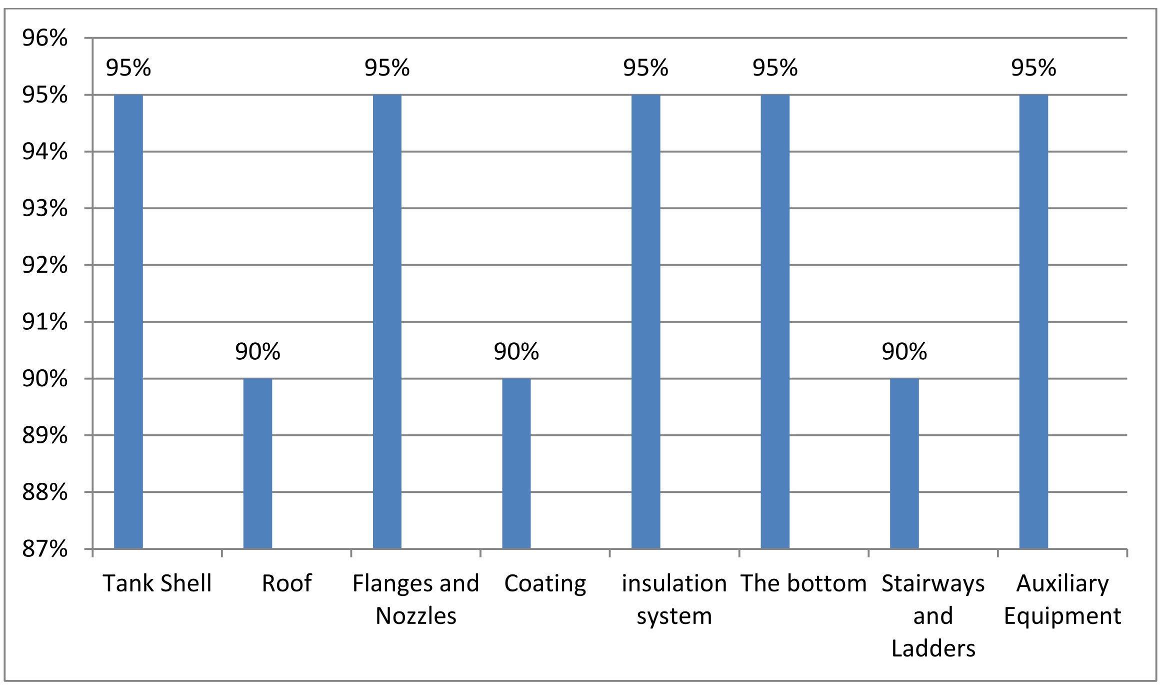

Figure 2: Inspection and maintenance of various parts

The information provided in the graph above shows that the parts that most of the oil and gas companies equally perform inspection and maintenance procedures on all parts. The most frequently mentioned parts include the tank shell (95%), Roof (90%), Flanges and Nozzles (95%), Coating (90%), the Insulation system (95%), the bottom (95%), Stairways and Ladders (90%), and Auxiliary equipments such as vents, alarms and Gage connections (95%).

4.2.3 Maintenance and oil tank failure

Poor maintenance procedures have been blamed for catastrophic tank failures. This question sought to determine the level of agreement with the following statement, "Poor maintenance procedures are responsible for over 80 percent of catastrophic tank failures". The responses to this question are as summarized below:

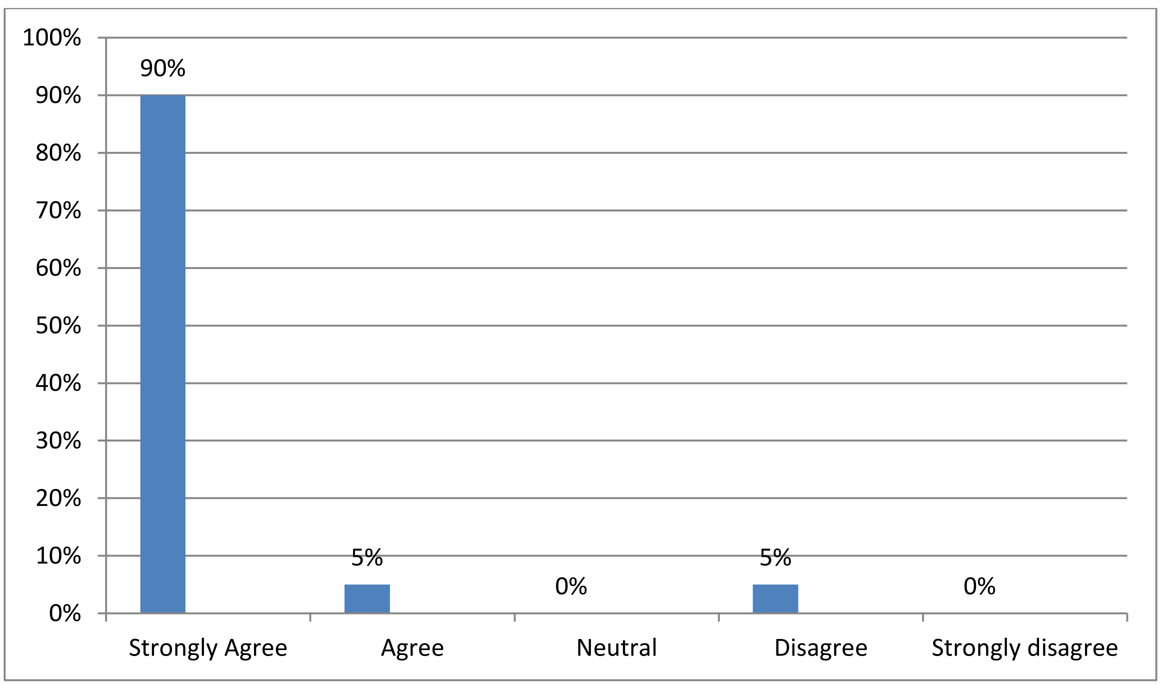

Figure 3: Levels of agreement

The responses above show that the respondents also agreed that most of the catastrophic tank failures are as a result of poor maintenance procedures. The responses can be broken down as follows: Strongly agree (90%), agree (5%), neutral (0), disagree (5%) and strongly disagree (0%). Based on these results, it is clear that the aggregate percentage of respondents who strongly agreed and agreed was 95%. This shows that poor maintenance procedures as a common cause of catastrophic tank failures has been supported.

4.2.4 Adherence to the API 653 standards

Despite the introduction of the API 653 guidelines in 1991, cases of tank failures have continued to be experienced. It is based on such occurrences that this question sought to determine the percentage compliance to these standards. The responses are as summarized in the graph below:

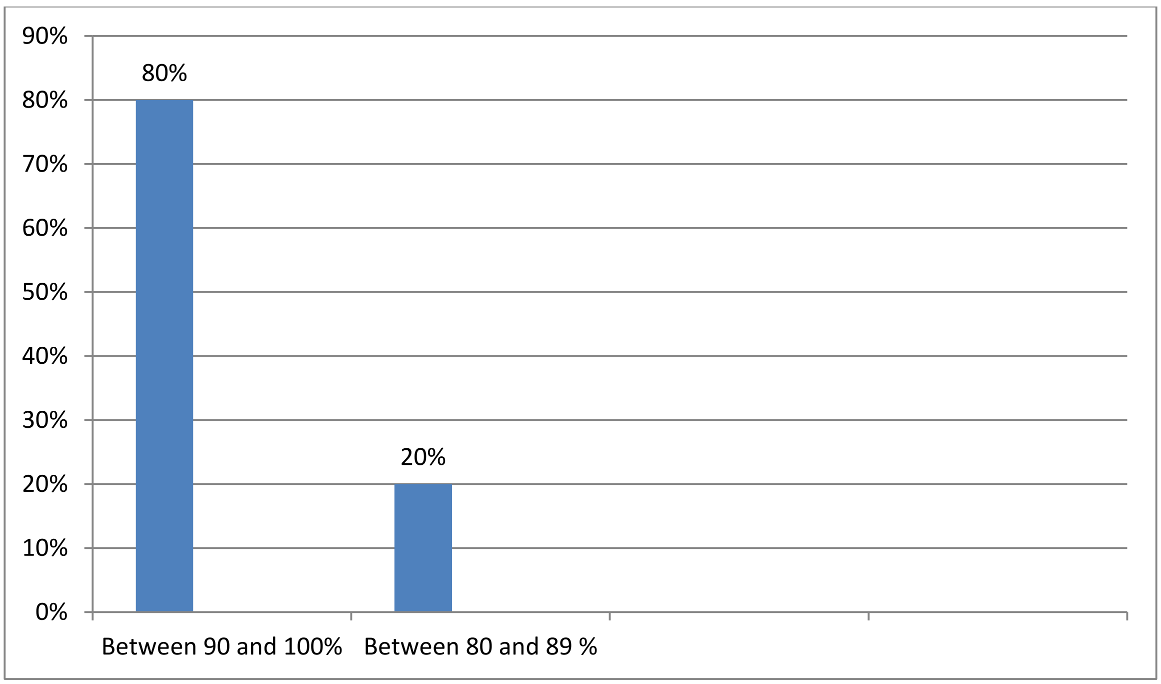

Figure 4: Adherence to API653 Guidelines

The compliance levels indicated in the graph above can be considered as “High”. This is evidenced by the least compliant company having a compliance level of between 80 and 90 %percent. Specifically, 80% of the respondents noted that they complied with between 90 percent and 100 of all the API653 guidelines. The remaining 20% respondents noted that their compliance level was between 80 and 89 percent.

4.2.5 Reasons for Partial Compliance

Referencing the responses provided in the previous section, it is evident that none of the companies has a 100 percent compliance rate. This question sought to determine some of the impediments to a 100 percent compliance level. The graph below summarizes some of the impediments to a 100 percent adherence as provided by the respondents.

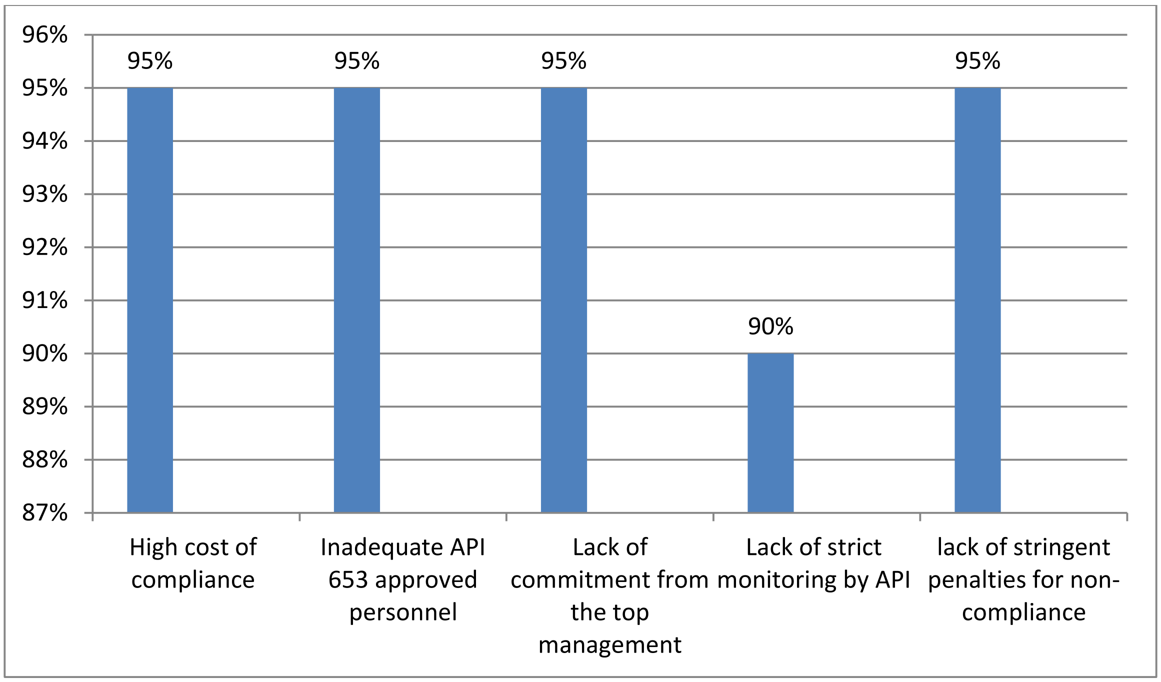

Figure 5: Reasons for partial adherence

The information shown in the graph above shows several reasons for partial compliance. These include high cost of compliance (95%), Inadequate API 653 approved personnel (95%), Lack of commitment from the top management (90 %), Lack of strict monitoring by API (90 %), and lack of stringent penalties for non-compliance (95 %).

4.2.6 Effects of API 653 Guidelines on Project Management

Oil and gas companies are large entities. As such, they make heavy investments in storage facilities/ tanks. This means undertaking inspection and maintenance procedures is deemed to be similar to any other large project. Therefore, it was important to determine whether the guidelines positively or negatively affected the project management procedures. To achieve this, this question sought to determine the level of agreement with the following statement, "API 653 guidelines have considerably improved oil and gas storage tanks inspection, maintenance and repair projects". The responses provided are as shown in the graph below:

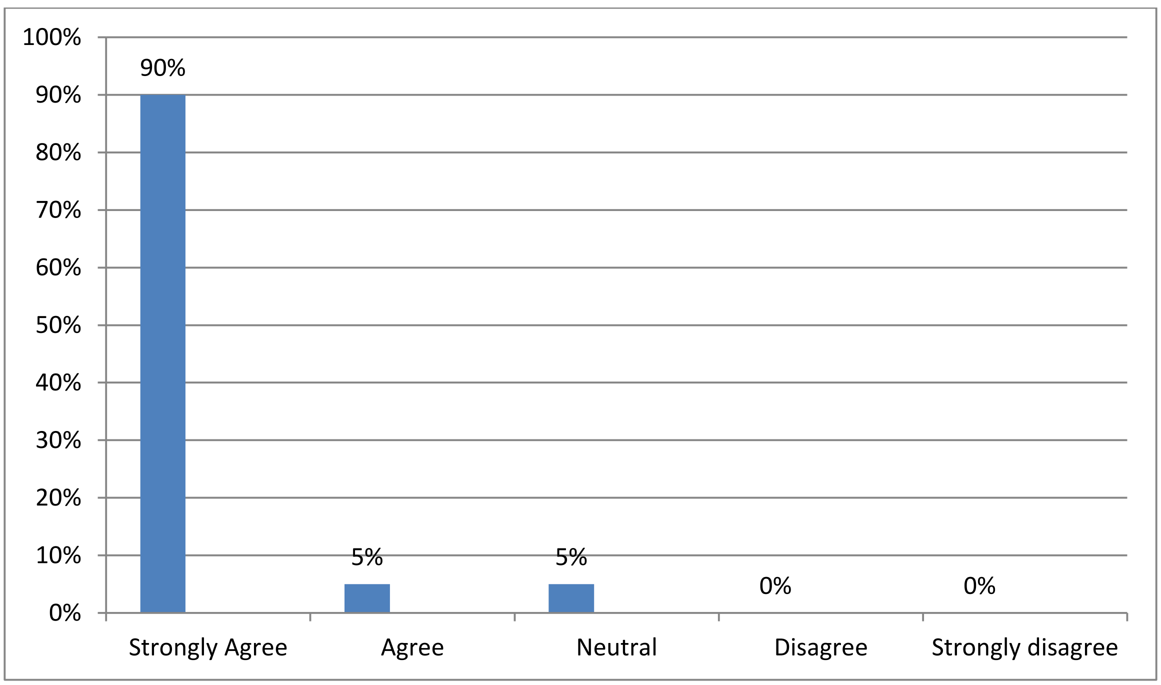

Figure 6: Effects of API 653 Guidelines on Project Management

The responses shown in the graph above indicate that the majority of the respondents agreed that the API 653 guidelines have significantly improved inspection, maintenance and repair procedures resulting in better outcomes. The findings were as follows: strongly agree (90 %), Agree (5%), neutral (5%), disagree (0%) and strongly disagree (0%). Based on these findings, it is evident that 95 percent of the respondents agreed that the guidelines have considerably improved the inspection, maintenance and repair outcomes. Therefore, it is justified to conclude that the guidelines have significantly improved the effectiveness and quality of maintenance procedures in the sector.

4.2.7 New Technologies in Inspection, maintenance and Repair Procedures

Similar to most of other areas, the effects of technological advancements have been experienced in inspection of oil storage tanks. The traditional approaches are no longer in common use because of their numerous drawbacks. The respondents stated various new technologies that they use during their inspection. The technologies are as shown in the graph below:

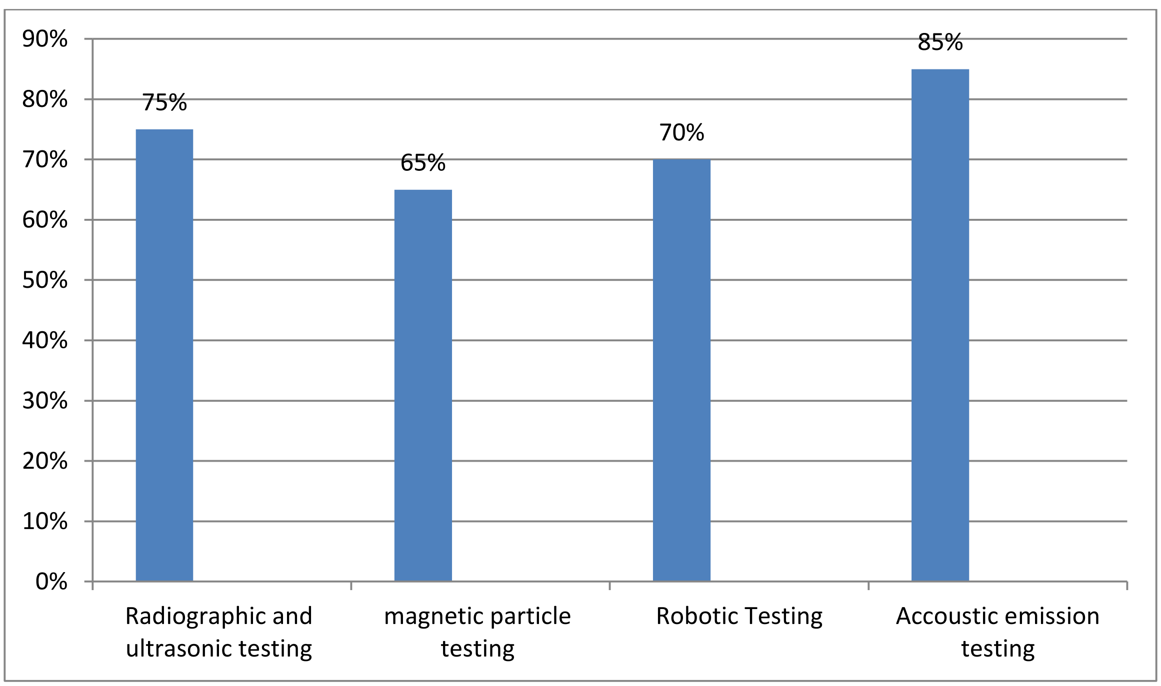

Figure 7: New Inspection technologies

The information above shows that all the modern inspection technologies are in common use. While in some cases, oil and gas companies apply only one of the technologies, application of two or more technologies is not uncommon as shown in the graph above. The degree of popularity as shown by the percentages is as follows: Radiographic and ultrasonic testing (75%), magnetic particle testing (65%), robotic testing (70 %) and acoustic emission testing (85 %). These percentages show that all the companies used at least two tank inspection methods.

4.2.8 Weaknesses In new inspection technologies

The new inspection technologies are considered to be highly superior compared to the traditional physical methods. However, there are various weaknesses associated with these new technologies. This question sought to identify the major weaknesses of these methods as identified by the respondents. The weaknesses are as shown in the graph below:

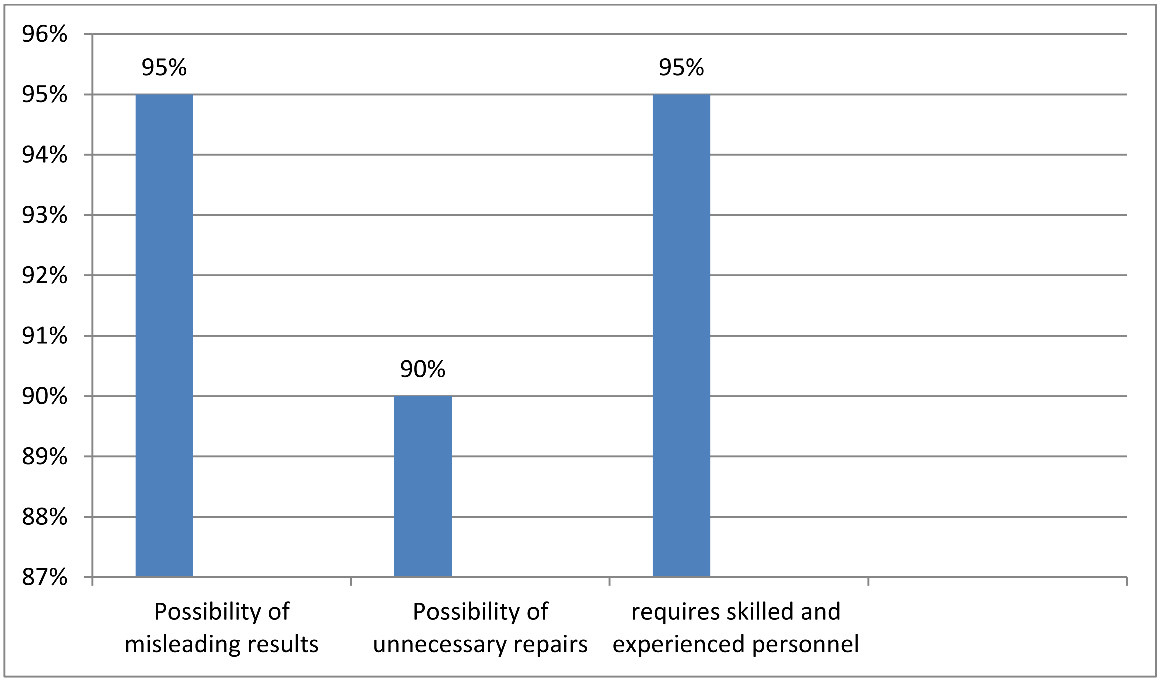

Figure 8: Weaknesses In new inspection technologies

The information shown in the graph above indicates that despite the new technologies being superior to the traditional methods, they have several disadvantages. The disadvantages shown can be considered factual because they were cited by at least 90 percent of the respondents. This shows a high level of consistency. The popularity of responses based on the number of respondents is as follows: Possibility of misleading results (95%), Possibility of unnecessary repairs (90%), and requires skilled and experienced personnel (95%).

4.3 Qualitative Analysis

Besides the results of the questionnaires presented in the previous section, interviews also captured vital information pertaining to the problem under investigation. This section provides the responses obtained through interviews. The sub-topics reflect the interview questions.

4.3.1 Profile of Interviewees

The three respondents interviewed were maintenance engineers. The years of experience for the engineers varied significantly. The 1st, 2nd and 3rd respondents had 15, 10 and 7 years of experience respectively. This shows the respondents were well experienced and knowledgeable. This increased their chances of providing reliable information.

4.3.2 Impacts of Poor maintenance Procedures

Inspection and maintenance procedures are proactive measures meant to prevent a failure. However, the ability to prevent these failures is determined by the quality of the procedures. According to the findings, poor maintenance procedures are the most common causes of catastrophic tank failures. These findings have been supported in the literature by Speight (2015), who argues that shoddy maintenance procedures have continued to cause avoidable tank failures. The high correlation between the findings and literature is a confirmation that the nature of inspection and maintenance procedures performed on a tank considerably influences their structural integrity and subsequently their likelihood of failure. The following analogy can be used to explain the relationship between these procedures and the risk of tank failure. The two main reasons for conducting inspection and maintenance procedures are to identify the presence of any leaks and corrosion and address them before they intensify and cause failure. Supposing shoddy inspection work was done and failed to detect the presence of corrosion at the initial stages. This would result in progressive wear which would compromise the structural integrity of the tank over time. The eventual result of this is a catastrophic failure.

4.3.3 Types of Maintenance

There are different types of maintenance practices which can be performed on oil storage tanks. The most commonly used types include the corrective maintenance, preventive maintenance, and predictive maintenance. This question sought to determine the popular maintenance procedures in the gas and oil industry. The responses are as provided below:

The 1st respondent noted that, "*the high risk nature of the industry compelled us to use both the preventive and the predictive maintenance procedures. Corrective maintenance cannot work in our case because the consequences would be dire.* "

The 2nd respondent observed that "*we use preventive maintenance in our facility. This is through scheduled maintenance which ensures the condition of the tanks is assessed and the necessary maintenance procedures initiated*".

The 3rd respondent observed that, "*Corrective maintenance is not advisable in maintenance of oil and oil industry. This is because in most of the instances, oil and gas tanks are not usable after a failure. The instances of failure mostly results in fires reducing the tanks into shells. To avoid this, we always emphasize on preventive maintenance.* "

4.3.4 Need for Maintenance of storage Tanks

Inspection and maintenance are two areas that are greatly emphasized in the oil and gas industry. This is evidenced by the interventions of bodies such as API by giving guidelines that should be observed players in the sector. This question sought to determine the reasons why inspection and maintenance is given a very high priority in the sector. The respondents gave diverse views as provided below:

The 1st respondent noted that, "*the reason why inspection and maintenance is overemphasized in the oil and gas sector is because most of storage tank failures are attributed to poor inspection and maintenance procedures. This makes these procedures to not only be emphasized by tank owners, but also other external bodies*".

The 2nd respondent observed that, "*the consequences of an oil and gas tank failure are not felt by the owner of the storage tank. The consequences are far reaching because they can lead to environmental pollution. It is because of such reasons that prevention of such failures through inspection and maintenance is highly recommended.*"

The 3rd respondent noted that, "*the highly severe consequences of tank failure is the main reason why inspection and maintenance are overemphasized in the oil and gas industry unlike in any other industry*"

4.3.5 Effects of New technologies in project management

New technologies are designed to improve the previous procedures in any given field. This is applicable in oil and gas tank inspection, maintenance and repair projects. There are various new methods which have been introduced in the oil and gas industry. Some of the most common ones include radiographic and ultrasonic testing, magnetic particle testing, robotic testing and acoustic emission testing. This question sought to identify ways in which these technologies have improved inspection of oil and gas storage tanks. The responses provided are as detailed below.

The 1st respondent observed that "*the application of new technologies has considerably reduced the complexity and time taken in conducting inspection and other maintenance procedures. This is because the technology can perform the inspection faster than humans besides eliminating the need for managing a large number of personnel who would have otherwise been involved*".

The 2nd respondent noted that, "*Initially we had to rush inspection projects because they had to be performed when the tank was out of service. Fortunately, the new technologies give inspectors adequate time to comprehend because the tank does not have to be put out of service.*"

The 3rd respondent noted that, "*the new technologies have eliminated the burden of having to manage too many inspection personnel. The high number of personnel also meant that the entire process was quite costly. In short, the new technologies have significantly improved the overall project management procedures in inspection, maintenance and repair of oil and gas storage tanks*".

4.3.6 Weaknesses in API 653 Guidelines

Similar to any other policy or procedure, the API 653 guidelines may have attracted various views from the oil and gas companies. The owners of oil and gas companies may have noted weaknesses in these guidelines. When addressed, they would considerably improve the safety of the tanks besides increasing their lifespan. This question was designed to collect information about the weaknesses in the current API guidelines. The responses obtained from the three respondents are as follows:

The 1st respondent noted that, "*I believe that guidelines without close monitoring and stringent measures for non-compliance are not adequate. Despite these measures being implemented in the* *early 1990s, there is laxity on the part of the government with regard to monitoring and enforcement".*

The 2nd respondent noted that, "*Some of the requirements of the API653 are difficult to achieve or else may be achieved outside the schedule. For instance, every oil and gas company has a schedule stipulating the time when inspection and maintenance procedures should be done. The unavailability of API 653 certified personnel as per the requirements are likely to delay the inspection procedures which would be undesirable for the involved company*".

The 3rd respondent observed that, "*the guidelines are good. The only aspect that needs to be improved is the monitoring and enforcement. Enforcement will ensure that the tank failure cases being experienced currently are minimized*".

5 Discussion

5.1 Chapter Introduction

This chapter presents a detailed discussion of the results presented in the previous chapter. The discussion is done in reference to the study objectives and the literature review chapter. This comparative discussion helps determine if the findings add new information or confirms what has already been documented by other researchers. The chapter is divided into five major sections including the reasons for inspection and maintenance of oil Storage tanks, new Tank Inspection Technologies, Weaknesses of New Inspection methods, effects of API 653 Guidelines and New technologies of Inspection and Maintenance Procedures, and methods of improving the API 653 Guidelines.

5.2 Reasons for inspection and maintenance of oil Storage tanks

The oil and gas industry has been portrayed as a complex and high risk industry. This is because of the nature of the products it deals with: oil and gas products. These products are highly inflammable and severe environmental pollutants. These are some of the reasons why effective inspection and maintenance cannot be underemphasized. The survey and literature cites several reasons why inspection and maintenance procedures are given priority in the oil and gas industry. According to De Simini and Raymond (2010), the main reasons for inspection and maintenance include identifying problems and initiating remedial measures, reducing the chances of catastrophic failure, and preventing the high costs of repair following and actual tank failure.

The above reasons have been replicated in the survey findings. The three interviews basically cited one general reason for inspections and maintenance in the industry. The reason is to prevent the severe consequences of failure. This reason captures all the reasons provided in the literature. Severe consequences can be the high costs that would be incurred during repair, the environmental pollution that would be experienced, and the legal suits that the failure would attract from affected persons. Based on this argument, it is correct to infer that the findings confirm the reasons provided in the literature.

5.3 New Tank Inspection Technologies

The literature chapter provides various new technologies currently used in the oil and gas tank inspections. According to Schempf et al (2005), Papasalouros et al (2011) and Javadi et al (2013), the most commonly used technologies in inspection of storage tanks include Radiographic and ultrasonic testing, magnetic particle testing, robotic testing and acoustic emission testing. These methods were also cited by the respondents. This shows there is a great relationship between the information provided in literature and the survey findings.

The literature provides various reasons why the above new technologies are suitable are more suitable than the traditional inspection methods. According to Schempf et al (2005), the main reason that makes these new technologies outstanding is that inspection is done while the tank is still in service. The implication of this is that the normal service of the tank is not interrupted. This is an argument that was confirmed by the respondents. They noted that new technologies use sensors which eliminate the need for extensive human interventions. This means that normal operations on the tank can continue uninterrupted. The information drawn from both the literature and the surveys shows a very great level of similarity. It is based on this high degree of similarity that justifies the conclusion that the findings confirm what has been provided in the literature.

5.4 Weaknesses of New Inspection methods

The findings revealed several weaknesses of the new oil tank inspection methods. These weaknesses have been confirmed in the literature. This strong correlation between the findings and literature is an indication of reliability. However, the weaknesses are not universal. Rather, every method has its own set of weaknesses. According to Loo and Herrmann (2009), a major drawback of acoustic emission testing is the lack of detailed reporting. This is one of the drawbacks provided by the respondents and this confirms its correctness. Inspections should produce detailed reports on which the inspectors can work on. Unfortunately, this is not the case with some of the methods such as the acoustic emission testing which only provides general qualitative information. A detailed report should capture aspects such as the depth and the size of the flaw in order to guide the determination of the urgency of remedial measures. General information is unacceptable because it can result in unnecessary repairs.

The need for skilled and experienced personnel is another notable drawback of these new technologies. This is a drawback which is captured in the literature and confirmed by the findings. According to Maelka and Kazys (2019), despite ultrasonic testing being among the most preferred testing methods, it requires highly skilled and experienced personnel if the correct results are to be realized. It is because of such complexities that the method can lead to unnecessary repairs. The implication of these drawbacks is that the advantages of ultrasonic testing can only be realized if experienced personnel are involved.

5.5 Effects of API 653 Guidelines and New technologies of Inspection and Maintenance Procedures

According to Yuan and Ting (2017), the API 653 guidelines were developed as a response to the increasing cases of oil storage tank failure. The goal was to standardize oil tank inspection and maintenance procedures using the most suitable tested methods. This means the goal was to address the problem whereby individual oil and gas companies had to develop their own guidelines and policies. Unfortunately, there have been no specific follow-up studies to determine the effects of these standardized guidelines on inspection procedures. The same case applies to the new technologies being used in inspection of storage tanks.

The findings in this study indicate that the guidelines and the new technologies have substantially contributed to the improvement of inspection and maintenance procedures. Based on the findings, the number of tank failure cases has significantly reduced following the introduction of the guidelines. The same argument has been given for the new technologies. This is because the technologies have a high accuracy level than physical inspections. As such, the reports generated when using the technologies can be relied upon to make well-informed decisions. This is an observation which has been provided in literature, though not emphasized. For instance, according to Papasalouros et al (2011), the new technologies have improved the quality of inspection and maintenance outcomes. This statement can be interpreted to mean that compared to the traditional inspection methods, the technologies have improved the efficiency and accuracy of all these procedures. Comparing this response and what is provided in literature, it is evident that there is some form of relationship between the two. Therefore, this serves as a confirmation that the use of these technologies is desirable to improve the quality of outcomes.

5.6 Methods of improving the API 653 Guidelines

It is evident from the previous section that the API 653 guidelines have considerably helped in reducing incidents of tank failure. Unfortunately, not all oil and gas corporations have fully adhered to the set guidelines. This is evidenced from the survey responses where the respondents cited a number of reasons why they though full compliance is yet to be achieved. These are reasons which have not been supported in the literature. This means they are new pieces of information added to the documented information.

One of the major reasons cited is the lack of monitoring from the API. Lack of monitoring can encourage laxity among the oil and gas companies who are supposed to implement these guidelines. This is particularly the case if the companies had their internal inspection, maintenance and repair procedures. This means there is a need for the API to come up with strategies of monitoring compliance with their guidelines.

The reason noted, is the absence of strict consequences for non-adherence. Based on the fact that the effects of tanks failure are felt even by parties other than the tank owners, it is important to have stringent consequences for non-adherence. This would serve to deter oil and gas companies or tank owners from deviating from the provisions of the guidelines. The overall result of this is high safety levels of storage tanks.

The third reason is the lack of adequate API 653 certified professionals. Insufficiency of these professionals can result in delayed scheduled maintenance. To avoid such delays, some of the oil and gas companies and oil storage tank owners can result to using uncertified but qualified professionals. It is important for the API to review their certification procedures to ensure there are sufficient professionals to meet the demand. This would considerably increase the adherence rates and thus increasing the overall compliance rate.

6 Conclusion and Recommendations

Inspection and maintenance of oil and gas storage tanks are very crucial exercises. The goal of these procedures is to prevent the catastrophic failures of oil and gas storage tanks. It is the severity of the effects of tank failures that motivated the API to develop standard guidelines to be observed by oil and gas companies and the storage tank owners. It is also the need for effective inspection and maintenance procedures that new advanced technologies have been developed. Some of the common technologies include Radiographic and ultrasonic testing, magnetic particle testing, robotic testing and acoustic emission testing.

- **To determine the effects of new technologies on Project management**

Inspection, maintenance and repair of oil and gas storage tanks can take several weeks or months depending on the nature of work. This means the works meet the threshold of a big project. As such, all the factors of project success/ failure have to be put into consideration. The most notable factors include time, cost, quality and scope. The new technologies have affected each of these aspects in the ways described below.

Quality of inspection and maintenance procedures is very essential. Shoddy procedures increase the risk of tank failure/ collapse. Fortunately, the new technologies have improved the quality of outcomes. They are more accurate than manual methods whereby inspectors had to rely on their eyes to detect any signs of corrosion or leaks. Therefore, they can be considered to have improved the quality of outcomes.

Time and cost of the projects have also been reduced considerably. The new technologies considerably reduce the time spent on inspection and maintenance procedures. This is because sensor-based technologies can complete the work within a short period of time, unlike human personnel who have to manually undertake the work. This is especially applicable when inspecting the bottom of the tanks which is not accessible from the outside. Additionally, only a few personnel are needed and this translates to cost savings.

Based on the above arguments, it is justified to conclude that the use of new inspection and maintenance technologies reduces the complexity of project management.

- **To determine the weaknesses of new Technologies**

In most of the cases, the maintenance of storage tanks in the oil and gas industry is condition based. Condition-based in this case means that maintenance is only done after an inspection has been done and the findings justify such procedures. Unfortunately, there are several weaknesses in the new technologies which can result in unnecessary maintenance procedures.

The technologies can give incorrect results and especially the technologies that use waves, such as the acoustic emission testing. The waves can be affected by the condition of the service environment such as noise.

These technologies also require skilled and experienced manpower. This is a challenge because of the high costs that may be incurred in hiring their services. This requirement may also result in the scarcity these personnel. This would affect the delivery of services as per the API 653 requirements.

The third weakness with some of these technologies is that some of them provide qualitative findings. This means they do not provide in-depth information about the condition of the storage tank. These details may be required when deciding whether immediate interventions are need of they can wait longer. This is a common issue with the acoustic emission testing which does not provide any quantitative details. This can result in unnecessary and costly repairs.

- **To determine how the API 653 standard guidelines affect project management procedures during inspection, maintenance and repair of oil storage tanks.**

The API 653 guidelines stipulate the requirements that should be met and the areas that should be inspected and maintained. Prior to the introduction of these guidelines, oil and gas companies and tank owners maintained their internal procedures. Based on the findings, these guidelines have affected project management in the following ways.

The guidelines have been confirmed to work by the API. This means by using tested guidelines, the chances of high quality outcomes are very high. This is unlike in the past when oil and gas companies had to autonomously develop their guidelines based on what they thought was appropriate. These guidelines have therefore helped improve the structural integrity of the storage tanks thus reducing the cases of tank failure.

The guidelines have also helped build a culture of safety in oil and gas companies. This is because the guidelines are similar to all players in the oil and gas industries. Compliance with these guidelines nurtures a safety culture. Safety culture ensures that every employee voluntarily observes all safety precautions without being forced.

- **To recommend improvement measures for inspection, maintenance and repair of oil storage tanks.**

The API 653 guidelines have greatly improved inspection and maintenance procedures. The guidelines have been termed as suitable. However, the findings revealed that there is need to increase compliance by oil and gas companies and tank owners. Frequent monitoring and auditing is one of the approaches that can be used to improve compliance. These measures would deter companies and individuals owning oil and gas tanks from using non-standard approaches.

The findings also revealed the need for the API to certify adequate inspectors in order to meet the demand. The inadequacy of the personnel was one of the reasons attributed to non-compliance with the set guidelines. It is therefore advisable for the institute to remove the hurdles the inspectors face when looking for certification. This would increase the compliance level and subsequently increasing the safety standards of the storage tanks.

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Appendices

Appendix 1- Questionnaire

(Please respond to all the Questions Provided)

Section A: Personal Information (Tick Where Appropriate)

1. What is your gender
   i. Male
   ii. Female
2. What is your area of specialization?
   i. Maintenance Engineer
   ii. Electrical Engineer
   iii. Machine operators
   iv. Others
3. How many years of experience do you have in your area of Specialisation?
   i. 0-5 years
   ii. 6-10 years
   iii. 11-15 years
   iv. 16-20 years
   v. Over 20 years

Section B: Personal Information

4. Which parts do you prioritize in your inspection and maintenance procedures? (Please tick all that applies)
    i. Tank shell
    ii. Roof
    iii. Flanges and Nozzles
    iv. Coating
    v. The Insulation system
    vi. The bottom
    vii. Stairways and Ladders
    viii. Auxiliary equipments such as vents, alarms and Gage connections
5. What is your level of agreement/ disagreement with the following statement?, “Poor maintenance procedures are responsible for over 80 percent of catastrophic tank failures”
    i. Strongly agree
    ii. Agree
    iii. Neutral
    iv. Disagree
    v. Strongly disagree
6. What reasons can you give for partial compliance with the API653 guidelines?
    i. High cost of compliance
    ii. Inadequate API 653 approved Inspectors
    iii. Lack of commitment from the top management
    iv. Lack of strict monitoring by API
    v. Lack of stringent penalties for non-compliance

7. What are the effects of API 653 Guidelines on Project Management?

   Strongly agree

   i. Agree
   ii. Neutral
   iii. Disagree
   iv. Strongly disagree

8. What new inspection technologies have you ever used to ease inspection work?

   i. Radiographic and ultrasonic testing
   ii. Magnetic particle testing
   iii. Robotic testing
   iv. Acoustic emission testing

9. What weaknesses have you experienced in using the new inspection technologies?

   i. Possibility of misleading results
   ii. Possibility of unnecessary repairs
   iii. Requires skilled and experienced personnel

Appendix 2- Interview Questions

1. What is your gender
2. What is your area of specialization?

3. How many years of experience do you have in your area of specialisation?
4. What are the effects of poor maintenance procedures?
5. What types of maintenance procedures do you practice? (corrective maintenance, preventive maintenance, and predictive maintenance)
6. Why do you think it is important to periodically conduct maintenance procedures?
7. In what ways has new technologies affected project management?
8. In what ways do you think the API 653 guidelines can be improved?

Appendix 3- Consent Form

Consent Form for Participation in a research study

Title of the Study: Oil and gas industry tanks Inspection, maintenance and repair as per international Engineering standard and risk management in the project

Description

You are kindly invited to take part in this study whose overall goal is to enhance inspection, maintenance and repair procedures in the oil and gas industry. This is by considering the new technologies and the API653 guidelines and examining ways in which they can be improved.

Terms and Conditions of Participation

Participation is strictly on voluntary basis. There are no monetary benefits attached to your participation. You are also at liberty of withdrawing your participation at any time without providing reasons for your actions.

Consent

I have read and understood the conditions provided in this form. I hereby agree to participate.

Name……………………………. Sign………………………………….Date……………………