Corrosion Cost in Power Plants of General Electric Company of Libya

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Abstract

The corrosion prevention cost of utilities in power plants of the General Electric Company of Libya (GECOL) is estimated. The study cover expenses of tank coating, chemicals to mitigate corrosion and cathodic protection cost. The expenditure relative to the generated power is higher for steam power plants compared with gas and combined cycle power plants. Steam plants consume large amount of chemical materials to control corrosion in boilers and other utilities. Cost of tank coating is higher in steam plants because of the larger number of tanks needed to store fuel.

Key words: Cathodic protection, Coating, steam power plants, gas power plants, combined cycle power plants

Introduction

The impossible avoidance of corrosion costs is a well-known economic fact; this is due to the nature of corrosion process which is an electrochemical phenomenon that affects materials year-around. Thus, corrosion is a problem that cannot be stopped completely, but it is possible to reduce the economic damage by implanting corrosion and monitoring policies. Estimating the cost resulting from corrosion in different sectors and facilities at periodic time intervals will help developing a better vision for monitoring progress in combating the corrosion problem and the effectiveness of this spending.

Corrosion control requires expenditure on different methods which are considered as a direct cost while corrosion usually results in indirect cost as well.

Direct costs associated with corrosion are substantial. These include the selection of more expensive, corrosion-resistant materials for equipment and infrastructure, Gerhardus H. et al., 2002 [1], Y.F. Cheng, 2018 [2], as well as the implementation of corrosion control measures such as coatings, inhibitors, and cathodic protection, Pierre R. Roberge, 2000 [3], Y.F. Cheng, 2018, [2]. Additionally, operating costs may need to be adjusted to reduce corrosion rates, such as modifying water chemistry in power plants or oil refineries, Gerhardus H. et al., 2002 [1], Roberge, P.R., 2007 [4].

Indirect costs of corrosion can be even more significant. These encompass the expenses related to inspection, maintenance, and repair of corroded components, NACE International, 2016 [5], productivity losses, service disruptions, environmental damage, and safety-related incidents, Gerhardus et al., 2016 [6].

The adoption of appropriate corrosion mitigation and control strategies, such as cathodic protection, coatings, and inhibitors, can significantly reduce the costs associated with corrosion, Bhandari et al., 2015 [7]; Revie, 2015 [8]. These strategies can extend the service life of assets, reduce maintenance requirements, and minimize the risk of failure, Gerhardus et al., 2002 [1]; Hou et al., 2017 [9].

The General Electric Company of Libya (GECOL) providing electricity nationwide by distributing the generated electricity from various power stations situated all over the territory of Libya. These power stations operated by fuel or gas and more recently combined cycle units are incorporated in the national network. Aboveground storage tanks (ABS) are one of the major utility components in power plants. ABS with varying capacities are used to store various materials including operating fuels and water for different applications. Without proper protection, these tanks will suffer from corrosion attack either due to environmental conditions or from the stored materials. All tanks in all power stations are coated to provide the required protection against corrosion.

The survey includes also the cost of chemicals used by the GECOL to combat or mitigate corrosion problems in other facilities such as boilers and turbines. Cost of Cathodic (CP) Protection also included in this survey.

The Scope of this study is to cover direct costs only — excludes indirect costs like downtime or productivity losses- for the major facilities in power plants of GECOL such as above ground storage tanks and boilers.

Corrosion is a persistent challenge that affects a wide range of industries and infrastructure systems worldwide. The economic impact of corrosion is vast, with numerous studies highlighting the significant financial burden it imposes on businesses, governments, and society as whole.

Previous Studies on Corrosion Cost Estimation

Previous studies on the cost of corrosion have been conducted by various countries, reflecting a global recognition of the economic impact of corrosion on infrastructure, industries, and national economies. Among the countries that have undertaken comprehensive studies on corrosion costs are the United States, the United Kingdom, Japan, Australia, Kuwait, Germany, Finland, Sweden, India, and China NACE 2016 [5], Uhlig, H.H. 1949 [10]

The first systematic study on the cost of corrosion was performed in 1949 by H. H. Uhlig [10]. Uhlig estimated the annual direct cost of corrosion in the United States to be 5.427 billion US dollars (2.1% of GNP, gross national product, at the time), by summing the costs related to anti-corrosion materials and corrosion-induced maintenance and replacement. This original report also highlighted the significance of the indirect cost of corrosion and the cost incurred through over-design. The approach described in Uhlig's report, known as the Uhlig method, was adopted by Japan in 1977 and 1999 [11], and again in the United States in 1998

According to a seminal study by NACE International, the global cost of corrosion was estimated to be approximately $2.5 trillion in 2013, equivalent to around 3.4% of the global Gross Domestic Product (GDP), NACE International, 2016 [5]. In the United States alone, the cost of corrosion was estimated to be $276 billion annually, or around 3.1% of the country's GDP, Koch et al., 2016 [1].

Methodology

The annual direct cost of corrosion at the General Electricity Company was estimated by adding the cost of corrosion control methods and services. The corrosion control methods studied included protective coatings, chemical treatment, and cathodic protection applied to storage tanks.

- **Protective Coatings**: – coatings are used to provide protection against corrosion of AST. These metallic substrates, mostly carbon steel, will corrode in the absence of the coating, resulting in reduction of the service life of the steel part or component

- **Chemical water treatment:** involves adding specific chemicals to water systems (like boilers) to prevent or reduce corrosion of metal surfaces. These treatments work by altering the chemical environment to make it less aggressive toward metals.
- **Corrosion Inhibitors** – A corrosion inhibitor may be defined, in general terms, as a substance that when added in a small concentration to an environment effectively reduces the corrosion rate of a metal exposed to that environment. Inhibition is used internally with carbon steel pipes and vessels as an economic corrosion control alternative to stainless steels and alloys, A particular advantage of corrosion inhibition is that it often can be implemented or changed in situ without disrupting a process. Y. Paul Virmani [12]
- **Cathodic Protection:-** Impressed current systems that apply a small electrical current to the metal, making it the cathode and protecting it from corrosion.

Data collection

Data collection was conducted through interviews with experts and supervisors in various power plants of GECOL. The process includes distribution of specially prepared questionnaires about tanks and boilers. Data on chemicals used in chemical treatment to mitigate corrosion such as inhibitors and oxygen scavengers were obtained from administrators at the General Electricity Company.

The estimation of corrosion cost in this study is mainly based on consumables such as the cost of paints and their applications for tanks, cost of chemicals for corrosion control and water treatment in various power plant facilities, as well as the cost of installing cathodic protection for tanks.

The total number of aboveground storage tanks surveyed in this study are 131 tanks with varying capacities and applications. The cost of protective coating for aboveground storage tanks includes: surface preparation, coating material cost (including losses during application), and application process. Price estimations for coating materials and processes were quoted from international accepted sources Baorong, H., et al [13].

The life of coating depends on the quality of surface preparation and other factors such as type of the coating system and the environment surrounding the structure or the component. With proper surface preparation and proper selection of the coating system, a life of 10-20 years can be achieved. In this report, the cost estimation is based on coating life of 10 years. [14]

Protective coating is an effective means of preventing corrosion. Tanks are susceptible to corrosion due to environmental factors and the materials they are stored in. Implementing a robust coating system helps create a protective barrier, protecting tanks from corrosive elements and extending their lifespan.

Chemical treatment is essential for steam power plants to maintain the integrity, efficiency, and longevity of the system. Adequate chemical doses should be regularly supplied to the plants especially for steam plants to control corrosive species such as dissolved oxygen and carbon dioxide, to prevent scaling and fouling and to control the pH. The cost of implementing cathodic protection for tanks was also survived in this study

Cost Estimations

Cost of Tank Coating

Protective coating is an important method for corrosion prevention. The AST in different power stations varies in capacities from 30 m^3 up to 20,000 m^3. Each tank is coated completely from the outside surface and internally up to 2 meters from the ground and 1 m from the top of the tank, therefore, the coating cost is related directly to the surface area to be coated. The cost (in American dollar) of tank coating is shown in Table 1 for each power station. The cost of coating includes the surface preparation cost, the cost of the coating materials including losses and the application cost.

Table 1: Cost of tank coating for surveyed power stations

No	Power station	Type of unit	No. of tanks	generated Power	Cost of tank coating ($)	Cost/power ($/MW)
1	Tripoli-	Gas	5	594	303,369.82	510.7
2	Khoms	Gas	2	1125	193,161.2	171.7
3	Ruwais	Gas	9	900	597,682.4	664.1
4	Zuetina	Gas	3	770	253,070.46	328.7
5	Sarir	Gas	7	855	374,986.12	438.6
6	Obari	Gas	8	640	405,142.49	633.0
7	Zahra	Gas	7	141	167,337.91	1186.8
8	Zawia	Combined	13	1455	557,366.91	383.1
9	N.	Combined	14	1735	669,340.02	385.8
10	Misrata	Combined	9	820	491,235.17	599.1
11	Khoms	steam	19	480	1,169,627.7	2436.7
12	Khalij	Steam	5	1400	1,020,308.7	728.8
13	Tripoli-	Steam	18	370	963,446.44	2603.9
14	Darna	Steam	9	130	419,847.86	3229.6
15	Fornaj	Steam	3		51,079.79	
Total			**131**		**7,637003**	

Knowing that the commodity of the GECOL is the generated electrical power, therefore, on this basis the cost of tank coating can be related to the generated power measured in Megawatt. Figure 1 displays the cost of tank coatings relative to the generated power.

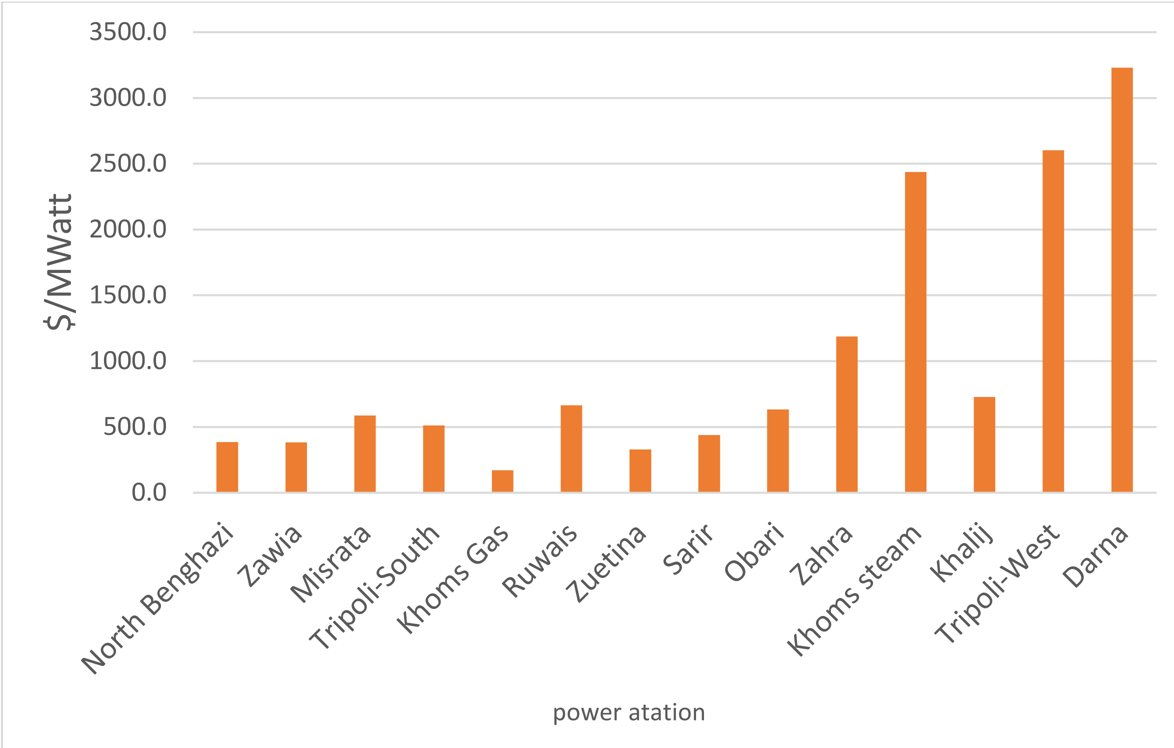

Figure: 1 Cost of tank coting relative to generated power (American dollar per MW)

Table 2 summarizes the data for all power plants by type of generating units.. The highlighted columns show the produced power and the cost of tank coating (in percentage) and represented graphically Figure.2. The relatively high productivity of combined cycle type generation units are evident as well as the lower cost of tank coating.

In gas generating power plants, the fuel is supplied through pipelines thus reducing the need for storage tanks to store the fuel unlike steam power plants where storage tanks for fuel is an essential facilities in power plants, thus despite the small number of steam units, the required number of tanks is larger than that for gas or combined cycle units.

The generation efficiency of combined cycle unit is higher than gas unites. Rolf Kehlhofer [15]. The combined cycle type of power plant exploits the heat from exhaust gases from gas turbine to generate steam for the steam turbine through heat recovery steam generator (HRSG)

Table 2: Data of power stations according to type

Type of unit	Number of		Production MW	Percentage of generated power	Tank Coating cost	percentage of coating cost
	units	tanks				
Gas	35	41	5025	44.02	2,294,750.4	30.0
combined	24	36	4010	35.13	1,717,942.1	22.5
steam	14	54	2380	20.85	3,624,310.49	47.5
total	73	131	11415	100	7,637,003.0	100

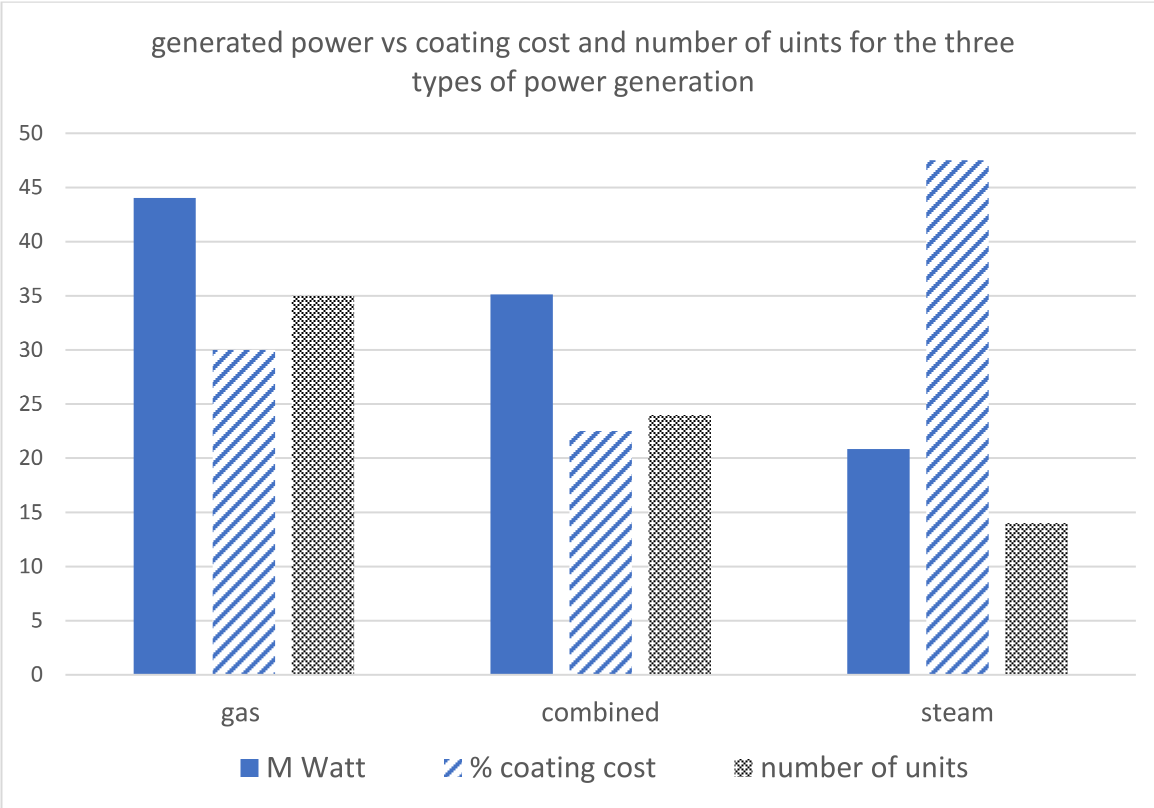

Figure 2: Graphical representation of the summarized data shown in Table 2

Cost of chemical materials

Table 3 shows the cost of chemical materials used by GECOL for all power stations. A substantial amount of this cost is spent in order to protect boilers and ensure long-live of this type of components and to produce quality steam to be passed to turbines. Steam power plants, in particular require a substantial amount of chemical materials for water treatment to ensure the preservation of boilers in an optimal working condition. This is because steam power plants encounter water-related challenges that need to be addressed, whereas gas power stations typically do not face such issues, consequently gas power stations require lesser amounts of chemical materials and thus lower expenses for corrosion prevention. The importance of controlling the pH and oxygen on corrosion is shown in Figure 3. [16]

Boilers in steam units require quality feed water for optimum operation. In desalination units, anti-scaling and oxygen scavengers are used. Carbohydrazide is added as an oxygen scavenger to boilers and condensate tubes. Tri-sodium phosphate added to control the pH and to prevent the formation of carbonate scale and ammonia for alkalinity control. [17]. Carbohydrazide decomposes to carbon dioxide and ammonia, although the corrosive effect from these two materials should negate each other, practically, the addition of Carbohydrazide to post-boiler section is necessary to avoid corrosion. [17]

Table 3: Type, quantities and cost of chemicals used in power stations and Desalination units

- ❖ Desalination evaporators

Material	function	Consumption ton/year	Cost €/ton	Total cost €
Belgard 2030 EV	Anti-scaling And Antifoulant	212	2465	522580
Sodium Sulphite Anhydrous	Oxygen scavenger			

- ❖ Boilers

Material	function	Consumption ton/year	Cost €/ton	Cost €
Belit AF 10	Anti-foam	5	5350	26750
Carbohydrazide	Oxygen scavenger	140	5395	755300
TRI-Sodium Phosphate	To prevent scale formation and pH control	20	1495	29900
Ammonia Hydroxide		20	675	13500

❖ Turbines

material	function	consumption ton/year	Cost €/ton	Cost €
Nalco TRC109	Corrosion inhibitor in cooling system			
Ferrous Sulphate Heptahydrate	Protection against erosion	35	328	11480
Sodium Nitrite	Corrosion inhibitor			

❖ Water treatment units

material	function	Consumption ton/year	Cost €/ton	Cost €
Hydrochloric acid	To clean resins	260	394	102440
Caustic Soda	To clean resins	160	675	108000

❖ Other chemicals

Sodium Hypochlorite to kill sea water organisms, Potassium Hydroxide for cooling system

Total cost in Euro (€)	1569950=1774043.5 US Dollar

Although Hydrazine is a very effective oxygen scavenger, in recent years it has been replaced by Carbohydrazide due to the toxicity of the Hydrazine and the special procedures required for handling it. Using the Carbohydrazide is generally considered safer to handle but larger quantities are required to effectively remove oxygen from the system comparing with Hydrazine. This justifies the large consumption of this material and consequently the increased cost for using this material the cost of Carbohydrazide represents about 50% of the total cost of chemical materials. as noticed in Table 3.

Trisodium phosphate is used in conjunction with amine, the orthophosphate reacts with calcium and magnesium ions to form insoluble precipitates, which helps prevent scale formation and the volatile amines form a protective layer on metal surfaces to reduce corrosion. Proper amount of trisodium phosphate is added to the water for the pH control to avoid the alkaline corrosion. To minimize the silica transfer from the boiler water into the steam in medium or high pressure boilers. The boiler water pH is controlled at the upper limit of the control range. Using of trisodium phosphate require less amount of caustic when compared with mono sodium or Di sodium phosphate. [17]

Nitrite is an effective anodic inhibitor in closed systems, adequate dosage levels should be used to maintain sufficient concentrations to avoid pitting corrosion [18]

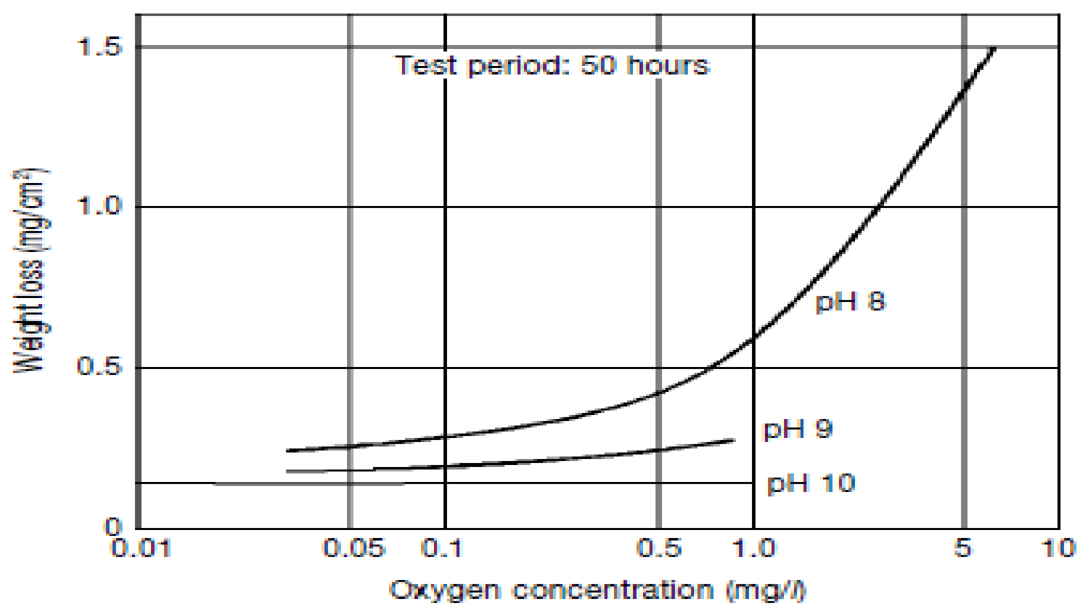

Figure.3: Influence of pH and oxygen on the corrosion of carbon steel in a high pressure and temperature water [16]

Cost of Cathodic Protection

The cost of cathodic protection (CP) implemented for tank bottoms is very small compared to the total expenses. Specifically, CP represents only 1% of the total costs. Table 4 provides details on the tanks that are cathodically protected.

The total annual cost of ICCP equals 15015*2.39=35886 US dollar. In total, there are 31 tanks that are cathodically protected, covering a total surface area of 15015.0 square meters representing about 28 % of the total bottom areas of all tanks.

The cost of cathodic protection represents only 1 % of the total cost. This low cost is because firstly the Impressed Current Cathodic Protection (ICCP) is a low cost prevention method and secondly ICCP has implemented to only about one quarter of the total area which should be protected.

It is well established that cathodic protection is a cost-effective and a reliable method to prevent or reduce corrosion. When Cathodic Protection is implemented for coated structures the coating live is extended for many years compared with structures not Cathodically Protected and it offers protection to holidays or damaged areas of coated surfaces. [20]

The cost of cathodic protection systems consists of initial establishment costs, operational costs and maintenance costs. The major criterion determining the costs is the current needed for the cathodic protection (using impressed current). [21]. Since all tanks in GECOL Company are coated, thus the needed electric current to implement cathodic protection for these coated is low, this would save cost due to reduction in energy consumption.

Table 4: Number of tanks cathodically protected and the sum of bottom areas protected of tanks

Power station	Number of tanks	Number of tanks protected by CP	Sum of bottom area protected (m^2)
Sarir	7	7	2468.8
Zahra	7	1	201.0
Zawia	13	7	633.1
N. Benghazi	14	6	404.7
Misrata	9	5	2258.6
Khalij	5	5	9049.0
total		31	15015.0

Cost of ICCP is rated at 2.39 (USD/m^2/year) [19]

Implementing CP is a low cost process with the benefits of extending the protective coating life and complementing the function of the protective coating to combat any local corrosion could be initiated due to defects in the applied coating such as holidays or damaged areas.

The cathodic protection is considered a low cost corrosion protection process relative to other protection measures such as protective coating for example. In protective coating, surface preparation and cost of coat application in addition to the relatively large losses of coating materials increases the total cost of this protection method.

Figure 4 compares the relative costs of cathodic protection, protective coating and construction cost for water tank. The figure shows the very lower cost of cathodic protection relative to the protective coating protection and to the overall cost.

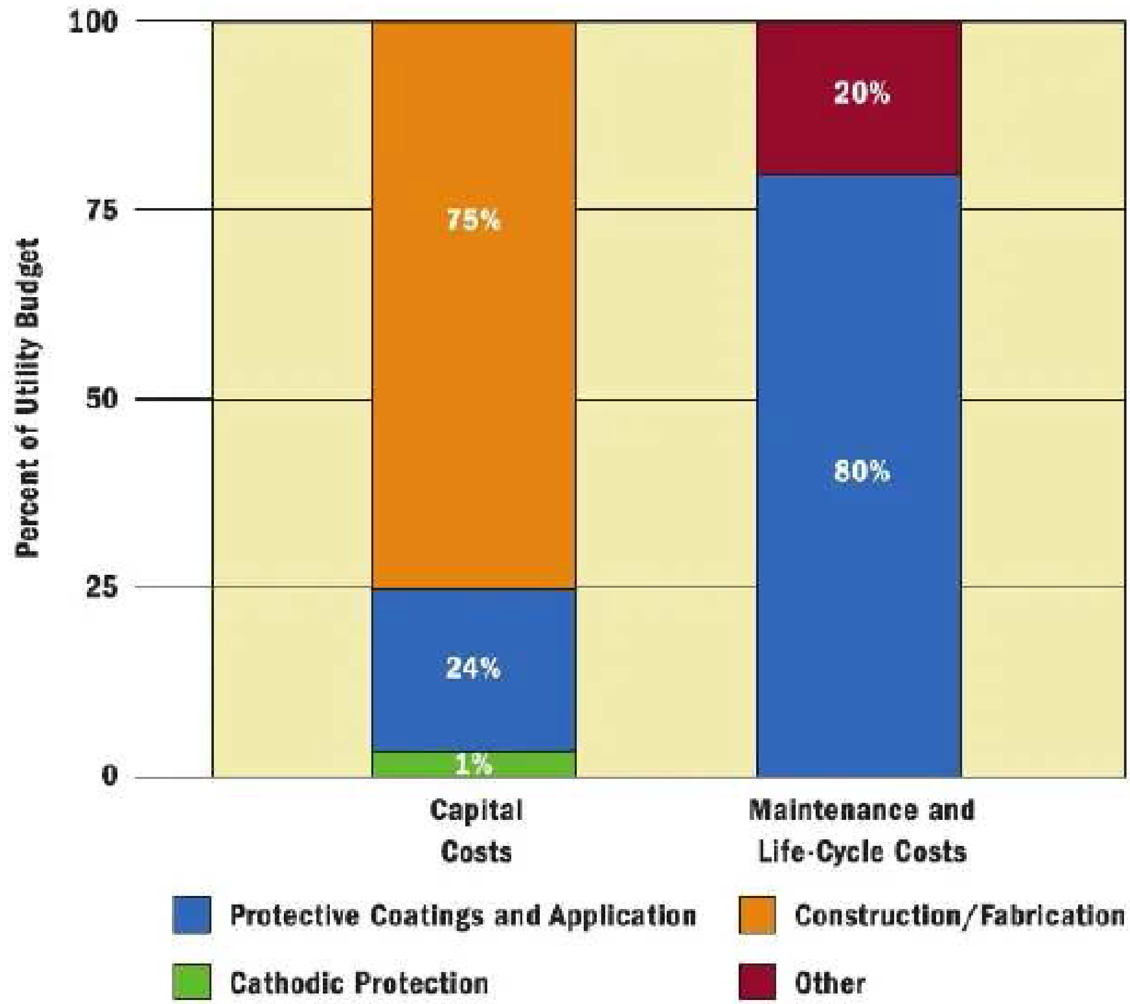

Figure 4: Relative cost of corrosion protection for water tank [20]

With regard to the gain that can be obtained by cathodic protection. Implementing cathodic protection is a cost-saving process, it complements the protection by protective coating and extends its life. [20]

The expenses of the three surveyed categories associated with corrosion mitigation at GECOL Company are summarized in Table 5. The overall cost is about **2.6** million

Table 5: Annual corrosion cost for GECOL company for all power stations

type	Cost ($)	percentage
chemicals	1,774,043.5	69%
Tank coating	763,700	30%
CP (tanks)	35,886	1%
total	2,573629.5	100%

Dollars per year. It is essential to note that the expenses mentioned above do not include additional costs such as shipping of materials and administrative expenses, which are not considered in this study. The cost of chemical materials accounts for a significant portion of the expenses.

Conclusions

- Coating cost for steam power plants is the higher than gas and combined cycle because of the increased number of required tanks and these units are less efficient when compared with combined cycle generation units.

- Using Carbohydrazide as an Oxygen scavenger to substitute Hydrazide has increased the cost of chemical materials because of the larger amounts needed to achieve the same results.
- The expenses of cathodic protection represent only 1 % of the total cost, this low figure is because only about 25 % of tank bottom areas has received ICCP.
- Implementation of CP would be very beneficial in combating corrosion to extend the service life of tanks and effectively contribute in reducing the corrosion cost due to coating.

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تكلفة التآكل في محطات توليد الطاقة التابعة للشركة العامة للكهرباء في ليبيا

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مستخلص

تم تقدير تكلفة منع التآكل في مرافق محطات توليد الطاقة التابعة للشركة العامة للكهرباء في ليبيا. تغطي الدراسة تكاليف طلاء الخزانات، والمواد الكيميائية اللازمة للحد من التآكل، وتكلفة الحماية الكاثودية. وتُعد تكلفة الطاقة المولدة في محطات توليد الطاقة البخارية أعلى مقارنةً بمحطات توليد الطاقة التي تعمل بالغاز والدورة المركبة. وتستهلك محطات توليد الطاقة البخارية كميات كبيرة من المواد الكيميائية للتحكم في التآكل في الغلايات والمرافق الأخرى. وترتفع تكلفة طلاء الخزانات في محطات توليد الطاقة البخارية نظرًا لكثرة عدد الخزانات اللازمة لتخزين الوقود.

الكلمات المفتاحية: الحماية الكاثودية، الطلاء، محطات الطاقة البخارية، محطات الطاقة الغازية، محطات الطاقة ذات الدورة المركبة