INVESTIGATION OF AVERAGE LIFE OF UNDERGROUND STORAGE TANKS

By

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ABSTRACT

Corrosion in underground storage tanks has become an important issue which need to be figured out before any economical loss. The basic aim of the present work is to study the average life of underground storage tanks using suitable numerical model. Mean Time to Corrosion Failure (MTCF) model is the proven model for predicting the average life of the underground storage tanks based on soil and tank characteristics. In this present paper, the average life of underground storage tanks using MTCF model based on available experimental data of corrosion rate, resistivity and other characteristics of tank and soil has been determined. The estimated maximum MTCF is 27.3 years and minimum is 17.4 years. Hence, in worst condition the life of considered tank would be around 17.4 years and in best condition it would be up to 27.3 years. The predicted results are in well agreement with literature data as the tank failure from external corrosion ranged from 5 to 35 years. The MTCF can be used the best suitable model to determine the average life of the underground storage tanks.

Keywords : Corrosion, Mean Time to Corrosion Failure, Underground Storage Tanks.

INTRODUCTION

Petroleum and fuels are stored in tanks buried underground. Underground storage tanks are mainly made up of steel which is considered more economical. Corrosion is one of the main environmental concerns, and is continuously a critical issue for petroleum and chemical industries [1]. Underground storage tanks are susceptible to corrosion at its surface. Corrosion includes rusting, discolouration and tarnishing of the surface [2]. It can be reduced but cannot be stopped as it is a thermodynamically spontaneous reaction [3]. In rusting process, the metal is degraded to form ferric rust, a red-brown compound, which is a sure sign of electrochemical oxidation of the metal. Almost all metals, with the exception of gold and platinum, will corrode in an oxidising environment forming compounds such as oxides, hydrides, and sulphides [4].

The degradation of metals by corrosion is a universal reaction [4]. Metal loss from external corrosion reduces life of a tank and often results in ruptures. Rupture of underground fuel storage tank due to corrosion can result in fuel leaks and seepage into the ground with devastating ecological consequences [1]. It is important to realise the corrosive attack on a metal and hence, any modification of the surface or its environment can change the rate of corrosion. Clearly, maintenance of underground storage tanks should be in such a manner that corrosion does not result in an unscheduled interruption in the process [5].

The corrosion in storage tanks depend on many factors such as the soil resistivity, pH of soil, the moisture content of soil, etc. Many methods to estimate corrosion rate are available. Weight-loss measurement is currently the most direct and reliable method but time consuming and information limited. Electrochemical measurement, which tests faster with more information, can be used in the field detection combined with other methods, is a non-destructive, quantitative technique and a powerful tool for researching corrosion process [6].

In practical way, the corrosion rates are non-zero, hence, the threat of corrosion-induced failures is actually increasing with time. New technologies are developed which enabled to make improvements and repairs before failures actually occur to possible extent [5].

Paints coatings and cathodic protection are the main means employed to protect steel tanks against corrosion. Provided maintenance is adequate, there should be a little concern about corrosion. However, field observation reveals the maintenance procedures that are not always sufficient. Therefore, corrosion remains one of the dominant factors which leads to storage tanks' structural failures [7].

Need for Corrosion Model

A vast majority of these underground fuel storage tanks are made of carbon steel and coated to prevent corrosion and contamination of stored product. But these steels have inadequate alloy additions to be considered corrosion resistant, aside, all coatings contain some defects that expose the tank and thus which undergo a variety of corrosion failure models in underground environments, including general corrosion, pitting corrosion and stress corrosion cracking [1].

Considering these failures, corrosion models are used. One of the corrosion models is MTCF (Mean Time to Corrosion Failure).For tanks installed for more than 10 years, a corrosion model test was conducted to examine the soil environment around the tank and its relationship with the metal underground storage tanks. A statistical model was used to evaluate the relationship between the aggressiveness of the environment and the rate of corrosion and to predict the remaining life of the underground storage tank prior to corrosion failure. An example of such method is Mean Time to Corrosion Failure (MTCF) [8].

Objective

Corrosion in underground storage tanks has become an important issue which need to be figured out before any economical loss. Hence, the basic objective of the present work is to be set as the investigation of the average life of underground storage tanks using suitable numerical model. As Mean Time to Corrosion Failure (MTCF) model is the proven model for predicting the average life of the underground storage tanks based on soil and tank characteristics, it has been used to determine the average life of underground storage tanks based on corrosion rate, resistivity and other characteristics of tank and soil.

1. MTCF Model

Numerous models are available to stimulate the rate of corrosion of underground storage tanks. In many cases, the actual underground storage tank is not available to measure the thickness of the tank wall directly, and/or it is not feasible to collect values for soil properties. In such cases, informed judgments are used, or a range of probable values is identified and used in corrosion model [9].

In 1979, a statistical method was developed for assessing and predicting the failure of unprotected steel Underground storage tanks based on soil variables surrounding the tanks [10]. The MTCF (mean Time to Corrosion Failure) model was originated from a survey of 2000 steel walled, non-cathodically protected underground storage tanks in US and Canada. By the late 1980s, the model had been used at over 22,000 sites in North America and subsequently refined based on observations following additional tank excavations [9].

Based on their study, the tank failure from external corrosion ranged from 5 to 35 years. The corrosion rate was not solely a function of tank age. The MTCF depends upon characteristics of the tank backfill material (e.g., soil moisture content, soil resistivity and sulfide content) along with the tank age. The model assumes that uniform and pitting corrosion are the primary corrosion mechanisms [11]. The MTCF Model is based on four model variables which affect the corrosion rate of underground storage tanks. Those variables are given by,

- chloride ions - causes the resistivity to be lower;
- soil moisture - primarily affects the activity of the chloride ions, if the moisture content is below 17.5%, the chloride ion concentration has a significant effect on the corrosion rate;
- pH - for lower pH (< 7.0) of the soil, the higher the corrosion rate, if the pH is above 7.0, the corrosion rate of the soil yields a longer service life;
- resistivity - follows the chloride ion concentration in that higher resistivity results in a lower chloride ion content and a lower corrosion rate.

The MTCF for an unprotected carbon steel underground storage tank without cathodic protection is described by an equation [9] as given by,

$$T_f = 5.57(R^{0.05})(S^{-0.017})\exp(0.12pH_{soil}) - 0.42M - 0.26S_u \quad (1)$$

where,

T_f is the mean age to leak, in years,

R is the soil resistivity in ohm-centimeter,

S is the capacity in gallons of the UST, in Imperial gallons,

M is related to the soil moisture content, where

1 is used if the soil is saturated,

0.5 if the soil is damp and

0 if the soil is dry, and

S_u is a factor related to the sulfide content of the soil,

where 1 is used if strongly present,

0.5 if trace amounts are present and

0 is used if no sulfides are present [12].

2. System Consideration

To study the MTCF model, available experimental data were used [13]. The experimental corrosion data were taken for seven pilot storage tanks, but only six storage tanks are considered. The tanks were fabricated from mild steel. These tanks were coated with corrosion resistant pigment red lead (Pb_3O_4). The tanks were cylindrical in shape with dimensions of diameter: 16.5 cm, height: 42 cm. The environments used for experimental study by them are given in Table 1.

The tanks were removed, properly cleaned, washed, dried and re-weighed after six months. The weight-loss technique [14,15] was used to calculate the corrosion rate as given by,

$$mpy(mills\ per\ year) = \frac{534W}{DAT} \quad (2)$$

The corrosion rate was estimated; where

W = Weight loss(mg)

D = Density of sample (g/cm3)

A = Area of specimen exposed to corrosion (cm2)

T = period of exposure (hours)

The corrosion rate, change in soil resistivity, density and pH for different period is given in Table 2.

Tank No.	Nature of various environments	Weight (kg)	Density (g/cm^3)	pH
Tank 1	Buried directly in Neutral Soil	8.13 kg	81.24	6.09
Tank 2	Covered with a cellophane material and buried in Neutral Soil	8.10 kg	80.94	6.03
Tank3	Buried directly in a soil infested in H_2SO_4	8.11 kg	81.04	5.50
Tank 4	Covered with a cellophane material and buried in a soil infested in H_2SO_4	8.13 kg	81.24	5.36
Tank 5	Buried directly in a soil infested in NaOH	11.00 kg	109.91	8.18
Tank 6	Covered with a cellophane material and buried in a soil infested in NaOH	9.00 kg	99.93	8.15

Table 1. Details of Underground storage tanks used for Corrosion study [13]

Tank No.	No. of Days			Average
	92 days	255 days	419 days	
Tank 1	20.09	20.63	22.27	21
Tank 2	17.89	20.56	22.27	20.24
Tank 3	17.81	18.73	20.06	18.87
Tank 4	17.49	18.84	20.44	18.93
Tank 5	25.32	26.65	28.72	26.9
Tank 6	24.39	25.49	27.30	25.73

Table 2. Details of experimental results of underground storage tanks [13]

3. Methodology

To determine the average life of underground storage tanks using MTCF model equation 1, the information of corrosion rate, resistivity and other characteristics of tank and soil are necessary as per equation 1. The available experimental data from literature for six different underground storage tanks have been considered as mentioned in Table 1. The average life of these six underground storage tanks have been determined by MTCF model using experimental data of density, corrosion rate, soil resitivity, and pH after 92, 255, and 419 days.

4. Results and Discussion

The average life of the underground storage tanks for six tanks using MTCF model were calculated based on experimental data [13]. The MTCF were calculated by considering the corrosion rate and soil resistivity data for 92 days, 255 days and 419 days respectively. The estimated MTCF are shown in Table 3.

The comparative bar chart for MTCF is shown in Figure1. It can be observed that there is no significant change in the value of MTCF for the data taken for different time period. The estimated maximum MTCF is 27.3 years and minimum is 17.4 years. Hence, in worst condition the life of

Tank No.	92 days			255 days			419 days			
	Density (g/cm^3)	CR (mpy)	SR (ohm-cm x 10^4)	Density (g/cm^3)	CR (mpy)	SR (ohm-cm x 10^4)	Density (g/cm^3)	pH	CR (mpy)	SR (ohm-cm x 10^4)
Tank 1	77.84	0.40	9.09	76.14	0.26	15.4	76.14	6.65	0.22	18.1
Tank 2	77.84	0.37	10.8	76.34	0.24	16.67	76.14	6.63	0.21	19.00
Tank 3	77.54	1.13	3.51	76.34	0.42	9.49	76.14	5.86	0.26	15.4
Tank 4	77.44	1.15	3.45	76.94	0.27	14.9	76.14	5.86	0.18	22.2
Tank 5	102.12	0.69	5.77	102.02	0.25	15.9	101.92	8.58	0.15	26.6
Tank 6	97.44	1.34	2.96	96.54	0.56	7.11	75.94	8.55	0.38	10.5

No. of Days

Table 3. Details of estimated MTCF in years

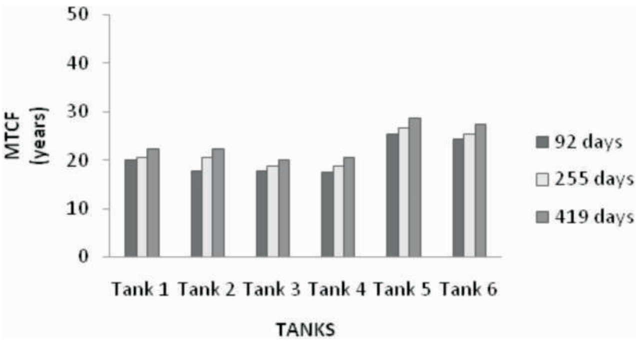

Figure 1. The comparative bar chart for MTCF

Concept	Industrial Process
Removal of oxidising agent	Boiler water treatment
Prevention of surface reaction	Cathodic protection - sacrificial anode - impressed current Anodic protection
Inhibition of surface reaction	Chemical inhibitors pH control
Protective coatings:	
a. Organic	Paint
b. Metallic	Claddings
c. Non-metallic	Electroplating Galvanising Metal spraying Anodising Conversion coatings
Modification of the metal	Alloys - stainless steel - cupronickel - high temperature alloys
Modification of surface conditions	Maintenance to remove corrosive agents Design to avoid crevices Design to avoid reactive metal combinations

Table 4. The different corrosion protection techniques [4]

considered tank would be around 17.4 years and in best condition it would be up to 27.3 years. The predicted results are in well agreement with literature data as the tank failure from external corrosion ranged from 5 to 35 years [11]. Hence the main finding of the present work is the applicability of MTCF model; it can be successfully used for the determinate the average life of the underground storage tanks.

Now-a-days, there are many new and advanced techniques for protection of underground storage tanks. Cathodic protection and effective coating are used to prevent the corrosion at surface of underground storage tanks [16] and either of them is effective [17]. They are known to increase the age of tanks. The different corrosion protection techniques are given in Table 4.

Application of corrosion inhibitors to underground storage tanks acts as an another protective measure. It is known that surface reactions are strongly affected by the presence of foreign molecules according to surface chemistry. Corrosion being surface reaction it can be controlled using inhibitors which adsorb on the reacting metal surface. Adsorption is the attachment of molecules directly to the surface. The technique of adding inhibitors to the environment of a tank is a well known method of controlling corrosion in many branches of technology. A corrosion inhibitor can restrict the rate of the anodic process or the cathodic process by simply blocking active sites on the metal surface [4].

Cathodic protection is very well known method of preventing corrosion on tanks situated in electrolytes. Practically, the tanks constructed of iron or steel (including stainless steel) are provided with cathodic protection where the electrolyte is soil. It has become a standard procedure for Underground storage tanks [18].

The long-term performance of a coating is affected significantly by its adherence ability to the material it is applied. As poor adhesion will allow corrosion products to undercut the coating film from areas of damage the tank. Coating experts often say Surface preparation is the most important factor in determining the success of any protective coating system as stated by coating experts

[19]. Many factors in surface preparation affect the coating which includes residues of oil grease, rust on the surface, etc which can decrease adhesion or mechanical bonding of coating to the surface of the tank [20]. For an organic coating, surface pre-treatment of the steel is most important. The pre-treatment consists of use of primers or coupling agents, solvent degreasing and acid pickling etc, which form a chemical bridge between the steel tank surface and the organic coating [21].

Conclusion

Corrosion in underground storage tanks is an important issue which need to be known before any loss. In present paper, attempt has been made to investigate the average life of underground storage tanks using Mean Time to Corrosion Failure (MTCF) model based on experimental data of corrosion rate, resistivity and other characteristics of tank and soil. 17.4 and 27.3 years are the minimum and maximum value of the average life of underground storage tanks respectively have been estimated by MTCF model. In worst condition the life of considered tank would be around 17.4 years and in best condition it would be up to 27.3 years for six underground storage tanks considered. Considering the determined average life of the tanks, they can be replaced before any inconvenience due to corrosion failure. The model results are in well agreement with available data as the tank failure from external corrosion ranged from 5 to 35 years. Hence, MTCF model can be recommended for the determination the average life of the underground storage tanks.

References

[1]. **Okiongbo K.S., Akpofure E., (2012).** Investigation of Soil Aggressiveness towards Underground Fuel Storage Tanks and Water Pipelines in Parts of Bayelsa State, Southern Nigeria, *Engineering*, Vol. 4, No.1, pp. 761-767.

[2]. **Speller F.N., (1951).** *Corrosion (Causes and Prevention)*, McGraw-Hill Book Company Inc., New York.

[3]. **Syed S., (2006).** Atmospheric Corrosion of Materials, *Emirates Journal for Engineering Research*, Vol.11, No.1, pp. 1-24.

[4]. **Wright G., (2014).** Chemistry Department, University of Auckland; Corrosion protection of metals, downloaded from "nzic.org.nz/ChemProcesses/metals/8J.pdf".

[5]. **Ricker R.E., (2010).** Analysis of Pipeline Steel Corrosion Data from NBS (NIST) Studies Conducted Between 1922-1940 and Relevance to pipeline Management, *Journal of Research of National Institute of Standard and Technology*, Vol.115, No.5, pp. 1.

[6]. **Zou Y., Wang J., Zheng Y.Y., (2010).** Electrochemical techniques for determining corrosion rate of rusted steel in sea water, *Corrosion Science* Vol.53, No.1, pp. 208-216.

[7]. **Qin S., Cui W., (2002).** Effect of corrosion model on the time dependent reliability of steel plated elements, *Marine Structures,* Vol.16, No.1, pp. 15-34.

[8]. **Title 41:** Fire Protection, chpt 1: Office of the State Fire Marshal, Part 175 Technical Requirements For Underground Storage Tanks And The Storage, Transportation, Sale And Use of Petroleum And Other Regulated Substances, Sect.175.510 *Corrosion Protection*.

[9]. **Morrison R.D., Murphy B.L. (2013).** Chlorinated Solvents: A Forensic Evaluation, *The Royal Society of Chemistry*, pp. 479-480.

[10]. **Morrison R. D., (2000).** J. Environ. Forensics, 200, Vol. 1, p. 131.

[11]. **US EPA (1999).** List of Integrity Assessment Evaluations for Underground Storage Tanks, Memorandum from Anna Hopkins of the Office of Underground Storage Tanks to State UST Program Contacts, 3rd edn, pp..

[12]. **US EPA (1978).** *Leak Prevention in Underground Storage Tanks*, EPA/600/2-87-018, pp.62.

[13]. **Owate I. O., Ezi C. W. I., Avwiri G., (2002).** Impact of Environmental Conditions on Sub-Surface Storage Tanks (Part I), *Journal of Applied Sciences and Environmental Management*, Vol.6, No.2, pp. 79-83.

[14]. **Fontana M.G., (1986).** *Corrosion Engineering*, 3rd edn McGraw-Hill, pp. 262-272.

[15]. **Craig B.D., (1989).** *Handbook of corrosion data*, ASTM, New York, pp. 62-70.

[16]. **Peabody A.W., (1967).** *Control of pipeline corrosion*, NACE, Houston, TX.

[17]. Jack T.R., Wilmott M.J., (2011). *Corrosion by Soils, in Uhlig's Corrosion Handbook*, ed. R. Winston Revie, A John Wiley and Sons, Inc., Publication, 3rd edn, pp. 346.

[18]. Bushman J.B., (2010). *Corrosion and Cathodic Protection Theory*, Bushman and Associates Inc., p.5, downloaded from "www.bushman.cc/pdf/corrosion_theory.pdf".

[19]. Deen K.M. and Ahmad R., (2009). Corrosion Protection Evaluation of Mild Steel Painted Surface by Electrochemical Impedance Spectroscopy, *Journal of Quality and Technology Management*, pp.1.

[20]. Bayliss D.A. and Deacon D.H., (2002). *Steelwork Corrosion Control*, 2nd Ed, Sponpress, London and New York, pp. 20-29.

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