

LININGS FOR ABOVEGROUND STORAGE TANKS

J.F. Delahunt
Carmagen Engineering, Inc.
7 Waverly Place
Madison, New Jersey

ABSTRACT

This paper describes the history and use of protective coatings applied to the internal shell and roofs of aboveground storage tanks in the petroleum and petrochemical industry. Such linings are employed to prevent corrosion, to protect product quality, to lessen product evaporative losses and to reduce tank roof seal wear. Described are corrosion mechanisms, corrosion rates as well as the development of inorganic and organic linings for hydrocarbon storage tanks. Advantages and disadvantages of such linings are included. Not discussed in this paper are linings for the floors of aboveground storage tanks which have been covered elsewhere.^(1,2,3)

INTRODUCTION

This paper traces the history and use of linings applied to the shells and roof of aboveground storage tanks in the petroleum and petrochemical industry. Their history of use begins before WWII and continues into the 1950's where testing and evaluation of the first modern coatings was initiated. In the early 1950's, the protective coatings in use included gunite, inorganic zinc rich silicates, and maintenance type of protective coatings. In the 1960's, epoxies began to be used as well as copolymers such as coal tar epoxy and epoxy-phenolics. Their use continues today as well as the newer protective coatings such as epoxy novolacs and others.

Storage tank linings may be used for several purposes. The first of these is corrosion control, a second is protection of product quality, third, to minimize evaporation of light hydrocarbon products and components, which results in environmental protection, and last, to reduce tank roof seal wear. These are

Copyright

highlighted in this paper as well as a discussion of corrosion mechanisms and rates. Internal storage tank corrosion depends upon many variables including: type of hydrocarbon stored; type of tank, i.e., cone roof, floating roof or internal floating roof; working of the tank, and environmental conditions. These factors are also discussed within this paper. However, to begin with, the different types of Above Ground Storage Tanks (AGST) will be described.

AGST - VARIOUS TYPES OF CONSTRUCTION

There are three primary designs of AGST in use today; they are Fixed Roof Tanks (FRT), which are frequently addressed as cone roof tanks, External Floating Roof Tanks (EFRT) and the newer Internal Floating Roof Tanks (IFRT).⁽⁴⁾ Open top tanks or reservoirs were used up until the 1950's but are no longer in use today. Primarily, this paper will be concerned with linings for EFRT and FRT tanks since much of the industry experience is concerned with these two types. The construction of the various AGST is describe below and schematically shown in Figure 1.

- FRT - The fixed roof or cone roof storage tank was developed in order to overcome the disadvantages of open top tanks. Open top tanks are no longer in use but were in service up through the 1950's or later. FRT provides for superior containment of the evaporative vapors but still does not suppress evaporation from the complete exposure of the stored hydrocarbon.
- EFRT - This type of tank with an External Floating Roof came into service about the 1920's. It was designed to significantly reduce evaporation losses common to FRT. It does this, as the name implies, with a roof that floats up and down as the liquid level within the tank rises and falls with the liquid level. This eliminates the vapor space. However, its disadvantages included the possibility of aggressive internal shell corrosion because of exposure to the elements and abrasion of the tank roof as it moves up and down during working of the tank. Another major concern is that the roof itself is exposed to ice, snow and rain, which has caused severe damage and sinking of the roof.
- IFRT - Developed in the late 50's and early 60's, an external roof protects the Internal Floating Roof from the elements and prevents lightening strikes. The external roof is a geodesic dome of mechanical construction. This type of construction minimizes evaporation losses and also, limits the exposure of the shell to the weather and that may reduce internal shell corrosion compared to an EFRT. Such data however, is not yet available.

Figure 2 shows a common seal design used for both FRT and IFRT tanks. These seals provide product conservation by minimizing evaporative product or light blending component losses. It consists of a metal shoe that rides against the shell of the tank. There is both a primary and secondary seal - the first is frequently an elastomeric fabric seal and a secondary elastomeric seal. Both can be changed out because of abrasive wear and deterioration during working of the tank.

STORAGE TANK SHELL CORROSION

The rate of internal corrosion of the shell of a EFRT storing light product depends primarily upon the geographic location of the tank and atmospheric corrosion that occurs at that location. For example, it was estimated that at Aruba NWI that in the past, internal corrosion of the shell in refined product tanks ranged from 10-20 mpy. At a refinery in the NE United States, shell corrosion in gasoline storage tanks was estimated at 6 mpy and in the Southeast Gulf Coast, corrosion was judged to be in the neighborhood of 15

mpy. In one location, internal corrosion of the shell was so severe that major repairs were required within two years.

The interior shell of a EFRT tank encounters corrosion much more severe than encountered by a carbon steel structure exposed in the same environment. The accelerated corrosion is caused by the floating roof moving up and down as the tank works and the steel shoe and the roof seals moved against the shell.⁽²⁾ This movement abrades and removes the existing rust or scale to some extent exposing "fresh" metal. Any light product such as gasoline or blending components evaporates quickly and atmospheric corrosion takes place. See Figure 3, which shows aggravated internal corrosion of the tank shell.

In an industrial location, such as N.E., an atmospheric corrosion curve shows a maximum rate of 4-5 mils per year in the first year, but after that the corrosion rate decreases rapidly to such an extent that total metal loss after 20 years is only 12-13 mils.⁽⁵⁾ This is a result of an oxide scale forming and to some extent, preventing the access of water and oxygen. See Figure 4. As discussed above, that does not occur in EFRT and a continuing high corrosion rate is encountered.

The results of such corrosion can be seen when the thickness of the various shell courses are measured. Frequently, the higher corrosion rates occur in the middle shell courses where roof movement is more frequent compared to the upper and lower shell courses.

The shell of a FRT in finished product service experiences less corrosion than the rate of that experienced in EFRT. This is because of less mechanical abuse because it is a fixed roof and also, the shell is not open to the atmospheric elements. Because of the relative newness of IFRT, there is little practical or measured corrosion rates. The author expects, however, that the rates may be somewhere between those experienced in a EFRT and a FRT tank.

Concerning internal roof corrosion, it is most frequently found in FRT tanks, especially where sour products or crude oils are stored. It effects not only the underside of the tank plate, but also on rafters supporting the roof. With EFRT tanks, corrosion on the underside of the roof may occur in the lap joints of the welded roof plates where there is a greater chance for water vapor condensation to take place and cause corrosion.

EARLY EVALUATIONS OF LININGS FOR EFRT SHELLS

During the early 1950's, evaluations were initiated to determine the effectiveness of linings applied to the shells of floating roof tanks. It was felt that several advantages might be achieved as follows:

- Reduced evaporation losses from "cling" of product to the shell
- Reduced evaporation losses from "creep" of product up the shell
- Increased life of floating roof seals
- Increased tank life because of reduced shell corrosion.

Extensive laboratory tests were undertaken⁽⁶⁾ in these areas with the results discussed in subsequent paragraphs.

Cling Losses

In the laboratory, testing was undertaken to determine the amount of motor gasoline that would cling to and then evaporate from the shell of EFRT simulating conditions that might be found in operating service. These surfaces varied from bare, smooth clean steel to heavily corroded steel and in situations where the shell would be internally protected with a thin film protective lining or a substantial gunite lining. The results of this investigation are shown in Table 1.

These results indicate that evaporation loss from impervious surfaces were negligible while from rusted steel, losses could be high, dependent upon the type of corrosion product encountered. Gunite linings were frequently used at that time, and would contribute extensively to evaporation loss.

Briefly, cling determinations were made by weighing test panels before and after immersion in gasoline. The heavily rusted panels were visually compared to in-service tanks at a refinery in the Northeastern U.S. and appeared to be very similar.

Creep Determination

Similar laboratory tests were undertaken to determine the amount of gasoline that would "creep" up the shell of a EFRT by either capillary and/or absorption onto various types of surfaces that might be encountered on a tank shell. The surfaces evaluated again included coated steel, abrasive blasted clean steel, and lightly rusted steel. It was concluded as a result of these investigations that there were no appreciable creep losses beyond a three inch liquid level to the atmosphere. Therefore, since the liquid level to the atmosphere for a floating roof tank considerably exceeds three inches, creep losses were considered insignificant.

Roof Seal Wear

After evaluating coefficients of friction, it was concluded that roof seal wear would be considerably greater in a FRT where the shell had been corroded and rust scale is present. See Figure 3. The coefficient of friction may be much larger for a corroded surface than a coated steel surface. It was estimated that depending upon the environmental location and working of the tank, seal life might be considerably extended if the shell is coated.

TANK SHELL LININGS PRIOR TO WWII

The use of coatings to internally line AGST's is not a new concept but dates back a number of years. In fact, protective coatings were first applied within storage tanks and refined product tankers about 1915. However, many were notably unsuccessful. Some of the coatings evaluated are listed in Table 2. Of these, the vinyl and gunite linings gave the best results and their use continued from the 1930's into the 1950's and 1960's.

Gunite linings were frequently used to line both shells and roofs of storage tanks and generally gave good service ... and it seems likely that there may be several gunite lined tanks still in use today. Specifications for applying gunite to tank internals were published as late as the 1950's. The life of gunite linings was variously estimated as between 15-20 years. They were used in water storage tanks, hydrocarbon storage tanks including the shells of floating roof tanks and also applied to the roofs of cone roof and floating roof tanks. However, there are drawbacks to the use of gunite such as:

- + Weight of dense concrete
- + Rapid wearing and deterioration of the seals of floating roofs
- + Difficult in gas freeing hydrocarbon storage tanks, resulting in safety problems

Based on such considerations, there was a continuing search for tank lining systems.

POST WWII LINING EVALUATIONS - EFRT

In the late 1940's and early 1950's,⁽⁶⁾ serious efforts were undertaken to determine the feasibility of lining EFRT with thin film protective coatings. Operators of tanks were surveyed in 1952 and at that time had applied the following thin film lining systems:

- Pipeline Company - Reported four years of experience with an air dried phenolic zinc chromate primer plus two top coats of a two compartment phenolic-aluminum lining system applied in 1946. The lining was in "fairly good condition" except where there was abrasion damage caused by the floating roof.
- Major Refinery - Five coat vinyl systems were applied in 1949; major deterioration and abrasion damage to four systems were reported after twenty months. However, internal shell corrosion was controlled and also, the tank roof seals were reported in good condition.
- Major Refinery - In-house generic phenolic coating systems had been applied since 1933 through 1949; One system failed over 50% of surface after three years service. In 1952, vinyl coating systems were being applied to replace the phenolic lining systems.
- Storage Tank Terminal - Conventional alkyd systems were applied in 1947; after five years service, the lining had failed over 75% of surface.
- Australian Refinery - "Galvanite" was applied in 1946 and reported in good condition over hand powertool cleaning. "Galvanite" was a heat cured inorganic zinc rich silicate coating (IZRC), later marketed in the U.S. as "Dimetcote No. 2."

At that time, abrasive blast cleaning was in its early stages of development and many of the above were applied to the shells cleaned by hand and power tools and then applied by brush or roller.

Coatings Application in the 1950's

Based upon the above, a number of coating systems were evaluated in-situ in an EFRT storage tank. These included thin film polyvinylchlorides and an early formulation of inorganic zinc rich coatings. In 1951, several were brush and roller applied to EFRT tanks in premium and also, regular grade gasoline service at a marketing terminal located in Wilmington, North Carolina. The linings tested in both tanks included the following:

- An inorganic zinc rich coating
- A five coat polyvinylchloride system
- A three coat air dried phenolic-aluminum system

- Three coat alkyd enamel system

The first was Dimetcote No. 2, the heat-cured predecessor of a Dimetcote No. 3.⁽⁷⁾ The Dimetcote No. 2 linings was heat cured at an average temperature of 350°F, which was achieved by flame curing on the outside shell of the tank. The next system listed was the Amercoat No. 23/No. 33 vinyl system, a first class vinyl system that was used extensively in chemical, marine, and water services. The next was Socony 11-A-6, a two compartment phenolic aluminum generally used in severe marine services, and the last was a Patterson Sargent alkyd coating system.

It was reported that large sections of the Dimetcote No. 2 failed during the first year. The failure of the IZRC occurred because of improper flame curing which was applied to the external surfaces of the tank steel. In addition, the alkyd failed rapidly, but the Amercoat vinyl system was in good condition.

Figures 5 and 6 show these systems in 1985. The Amercoat vinyl was in the best condition and the Socony 11-A-6 is still offering some protection. The terminal operator reported that about 35 years after application brush and roller marks were still visible.

Extensive Laboratory and Screening Tests Undertaken

Laboratory and screening tests were undertaken in the middle to late 1950's to evaluate the more recently developed coatings for use as shell linings in FRT. These included IZRC, amine-epoxies polyamide-epoxies, polyurethanes and epoxy phenolics. Many of the protective coatings selected for tests as potential tank shell linings were also being evaluated in the same time frame as linings for refined product tanker cargo tanks and had been screened for resistance to motor gasoline, aromatic hydrocarbons, alcohols and other products as well as resistance to alternating salt water exposed refined products.

With this as background, the laboratory tests undertaken are listed below:

- Abrasion Resistance - Initial and after exposure in aliphatic and aromatic hydrocarbons
- Resistance to digs and scrapes - Initial and after exposure in aliphatic and aromatic hydrocarbons
- Weatherometer Exposure
- Salt Spray Exposure

Of the systems tested, the most promising was a waterbased post cured IZRC and therefore, it and 11 other coatings were strip tested in an EFRT at a refinery located in the Southeastern U.S.

These were evaluated after a six month period of exposure and it was determined that all the epoxies and epoxy co-polymers were chalking badly. There was general creep corrosion occurring for all organic linings at high points of the shell where there was shoe abrasion and several showed indications of pinpoint rusting. The water based IZRC showed none of these problems and it was recommended for general application in EFRT tanks with an estimated life of 10+ years. Figure 7 shows an IZRC application to the shell of an EFRT in the 1960's.

IZRC Lining Performance Reviewed

IZRC tank linings are in use today with a remarkable coating history.⁽⁸⁾ However, at one location when there was general change to the ethyl silicate IZRC from the water based postcured or self-cured type the life of a single coat of IZRC was shortened to 3-4 years. This was attributed to the softer, less abrasion resistant film of the ethyl silicates and subsequently in locations, the change was made to ethyl silicate IZRC primer plus two epoxy-phenolic topcoats.

This change lasted again for 3-4 years, but problems were encountered when the epoxy-phenolic topcoats delaminated from the ethyl silicate IZRC prime coat. This brought about another change and that was to apply the epoxy-phenolic lining without the IZRC. This change occurred about 1970, so frequently today epoxy-phenolics or epoxy novalacs are used in new construction, especially when corrosion prevention and/or product purity is also required.

However, single coat, waterbased IZRC lining systems are recommended based upon their past history. For example, during construction of a new refinery about 1970, IZRC was applied to EFRT tanks in motor gasoline blending and finished product storage service. These tanks have never been relined and shell corrosion has been minimal.

TANK LININGS FOR SPECIALTY SERVICE

Linings are also used in the petroleum petrochemical industry for varied specialty services as discussed below.

- Water Storage - Linings are applied in FRT tanks in multiple water services such as dirty ballast water, river water, salt water, demineralized water and others. In demineralized water or boiler feed water, storage temperatures can range from ambient to about 200°F. Linings here can range from epoxy-phenolic and epoxy novolac coatings to glass flake filled vinyl esters. For dirty water or raw water storage, coal tar epoxies have been frequently used in the past. Because of the perceived safety problems with coal tar epoxy coatings, the use of this remarkable coating is decreasing and others are taking its place.
- Jet Fuel - Linings for jet fuel storage are generally selected from qualified purchasing lists for U.S. Military specifications or British Military specifications. IZRC should not be used because of possible product quality problems. Figures 8 and 9 shows epoxy-phenolic linings applied to the shells of EFRT in jet fuel service; abrasion by the roof seal is clearly evident.
- Specialty Products - IZRC coatings are also in use to protect product quality of specialty products, such as solvents and alcohols, when required.

LININGS FOR ROOFS OF STORAGE TANKS

There are internal corrosion problems associated with roofs of FRT and less frequently with EFRT tanks and these problems are difficult to resolve. Frequently roofs are fabricated from 3/8-1/4 inch thick carbon steel plates that are lap welded together and it is the open lap where corrosion is frequently detected as well as on the surface of the plate. However, when a roof is coated, the exposed plate can be abrasive

blasted clean and coated properly, but the lap cannot so that the lining fails almost immediately at this critical area location. Epoxy and elastomeric caulks have been tried without a great deal of success. One solution is to seal weld the overlaps, but this is expensive and not met with a great deal of enthusiasm.

The second problem encountered at the roofs are the rafters installed to support the roof. At the junction of the rafter and roof, it is impossible to blast and clean correctly so the general instruction usually is to raise the roof plate where possible and to do the best possible practical job. Since these rafters are not immersed in hydrocarbon, there has been some thought of blasting and coating where it would be effective and using a paste/petrolatum tape where it has not been properly prepared and coated. Another approach, because of continued corrosion of the carbon steel roofs, is to replace that roof with an aluminum geodesic dome roof.

CONCLUSIONS

Coatings and linings play a large role in preventing corrosion of storage tanks in the petroleum and petrochemical industry in a variety of tank designs and in a variety of services. In addition to their corrosion mitigating properties, linings also serve to prevent product quality problems, and to extend the life of tank seals. The selection of a protective coating depends upon a number of variables including local environment corrosion rates, product stored, type of storage tank and others. When properly applied, the lining can give a long durable life at an advantageous cost to the owner.

The underside of roofs have been coated with inorganic zinc rich coatings, coal tar-epoxies, epoxy phenolics, and epoxy-phenolics with life ranging from 3-10 years. This is a problem area and it should be carefully addressed. One potential solution is to replace the fixed carbon steel roof with an aluminum geodesic dome roof.

As with all lining applications, the success of thin film storage tank linings in refineries and petrochemical plants depends upon lining choice, surface preparation, application and inspection.⁽⁹⁾

ACKNOWLEDGMENT

The author wishes to acknowledge the permission of Exxon Research and Engineering Company to reference reports and other documents from over 40 years ago that aided immeasurably in resurrecting the history of internal linings for aboveground storage tanks.

REFERENCES

1. Sumbry, Louis C. "The Successful Application of FRP Linings in Above Ground Storage Tanks: A 20 Year History," *Journal of Protective Coatings and Linings*, March 1990, pp. 40-44.
2. Delahunt, J.F. "Coatings and Lining Applications to Control Storage Tank Corrosion," *Journal of Protective Coatings and Linings*, February 1987, p. 24.
3. Wyqant, J.F., et al. "Reinforced Plastic Replacement Tank Bottoms," ASME Mechanical Engineering Conference, September 23-26, 1962, Paper No. 62-PET-43.

4. Laverman, R.J., et al. "Emission Reduction Options for Floating Roof Tanks," "Second International Symposium on Above Ground Storage Tanks," Houston, Texas, 1992, CBT-5565.
5. Boyd, W.K., Fink, F.W. "Corrosion of Metals in the Atmosphere," Metals and Ceramics Information Center, Battele, Report No. MCIC 14-23, August 1974.
6. "Coating for Interior Shells of Floating Roof Tanks," Evaporation Committee, March 1952 Meeting, Standard Oil Development Company.
7. Munger, C.G., "The Dimetcote No. 3 Story," Ameron, Protective Coatings Division, November, 1978.
8. Munger, C.G., "Corrosion Prevention by Protective Coatings," National Association of Corrosion Engineers, 1984.
9. Schilling, M.S., "Thin Film Tank Linings," First International Symposium on Aboveground Storage Tanks, National Association of Corrosion Engineers, June 26-29, 1990.

Table 1
Cling Losses to the Shell of EFRT

<u>Shell</u> <u>Description</u>	<u>Cling Loss</u> <u>Bbls./1000 FT²</u>
Clean Steel	0.010
Light Rust	0.023
Heavy Rust	0.140
Dense Heavy Rust	0.088
Inorganic Zinc Coated Steel	0.010
Gunite, 1 inch thick	4.10

Table 2
Linings Evaluate Prior to WWII

+	Air dried phenolics
+	Baked phenolics
+	Litharge and red lead
+	Alkyds
+	Shellac
+	Polyvinylchloride
+	Gunite

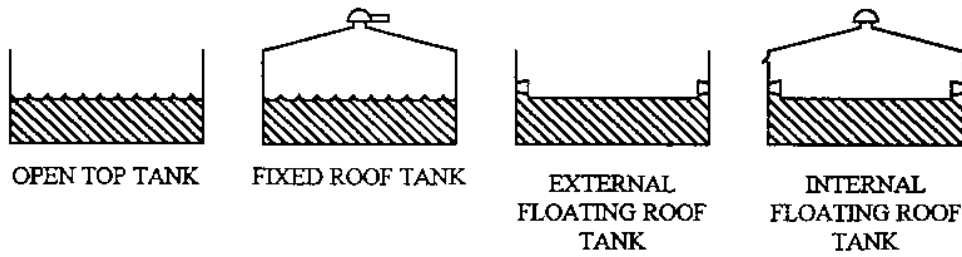


Figure 1

As shown schematically, is the construction of various types of aboveground storage tank construction. Open top tanks are no longer in use.

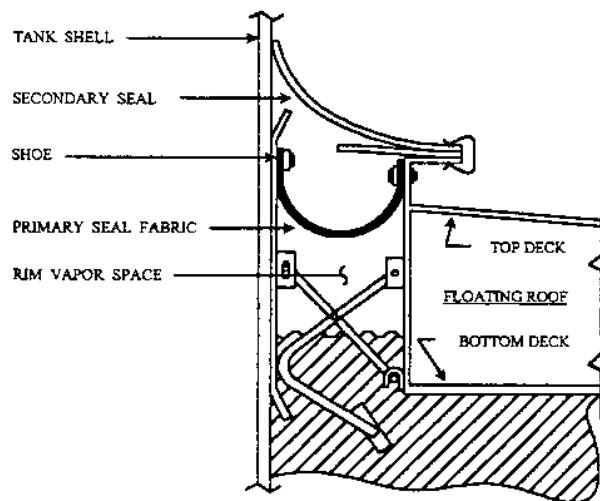


Figure 2

A schematic drawing of one type of seal used on floating roof tanks. As the seal moves with the roof, it will remove rust scale and exposes "fresh" metal to atmospheric corrosion.

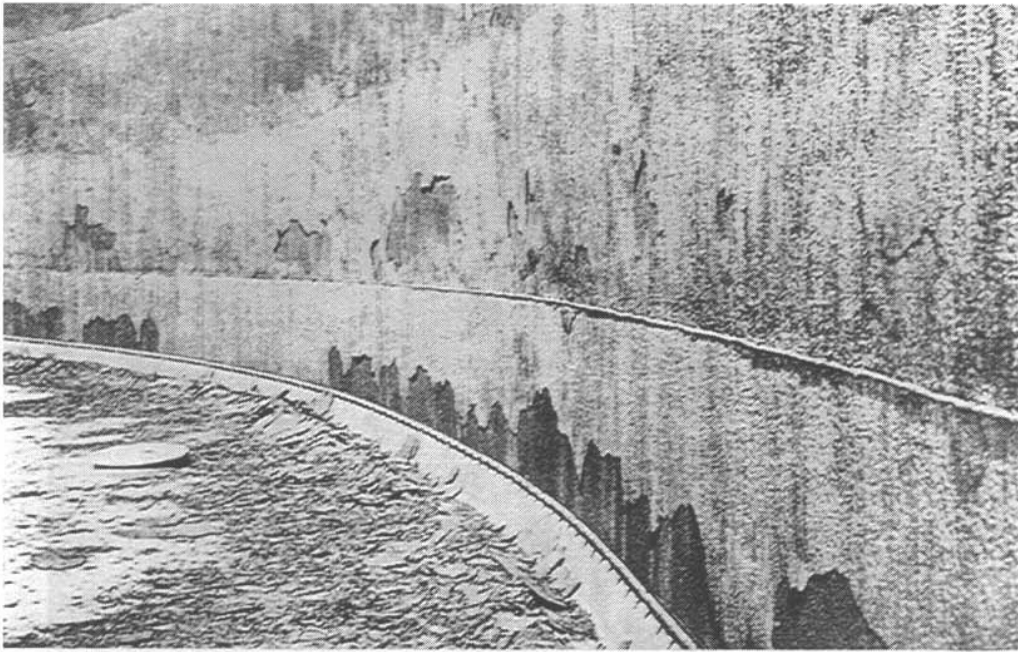


Figure 3

Photograph of severe corrosion and heavy rust scale of the internal shell of a floating roof tank four years after construction.

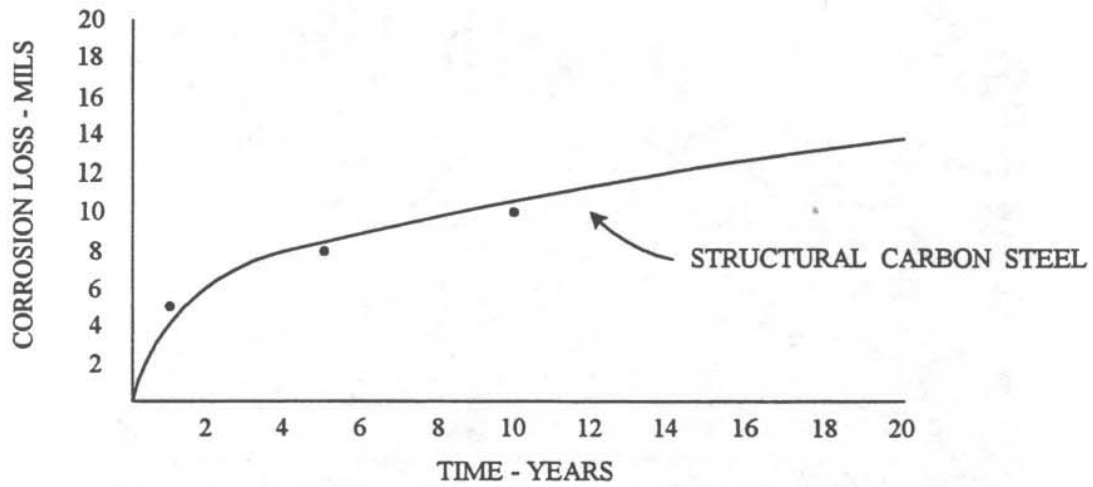


Figure 4

The atmospheric corrosion curve of carbon steel when exposed in a severe Northeastern industrial environment.

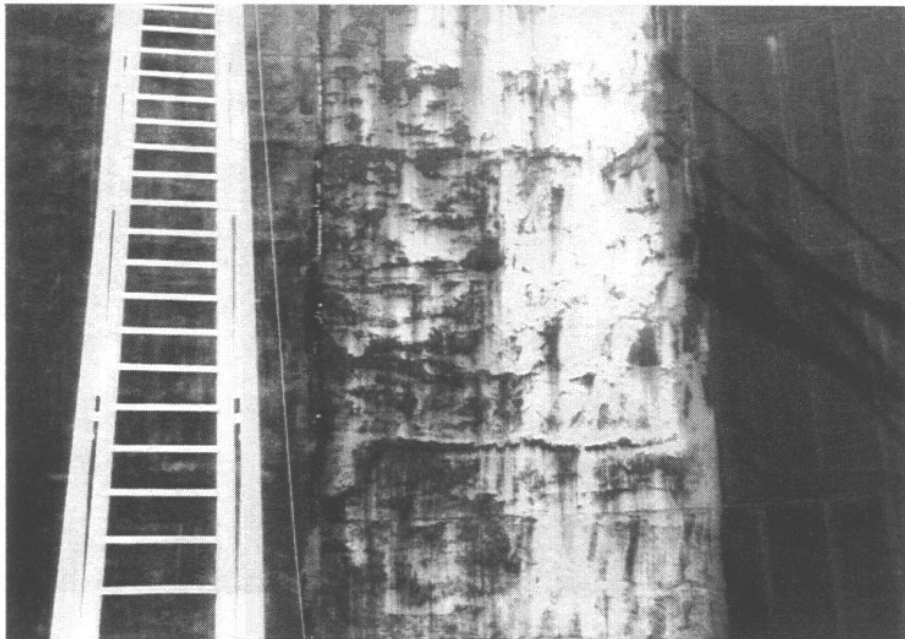


Figure 5

A photograph of the interior shell showing the condition of the protective coatings applied approximately 34 years ago. The phenolic coating system is shown in the center of the photograph and on either side is the vinyl system.

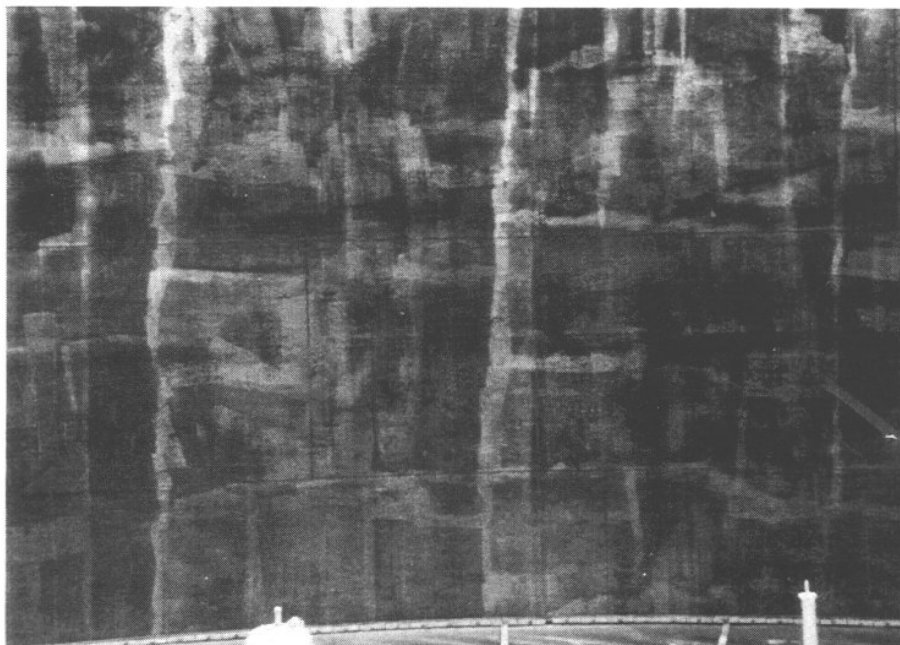


Figure 6

Another view of the vinyl system showing its protective value and also, the roller application marks.

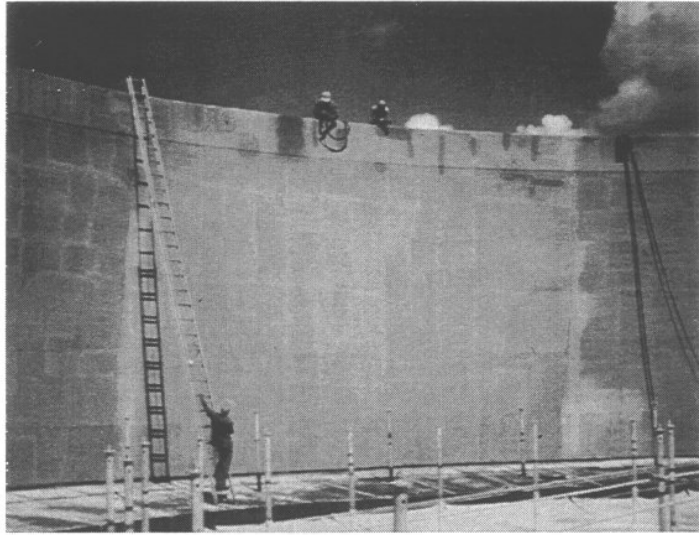


Figure 7

The shell of a floating roof tank after application of a postcured water based inorganic zinc rich coating.

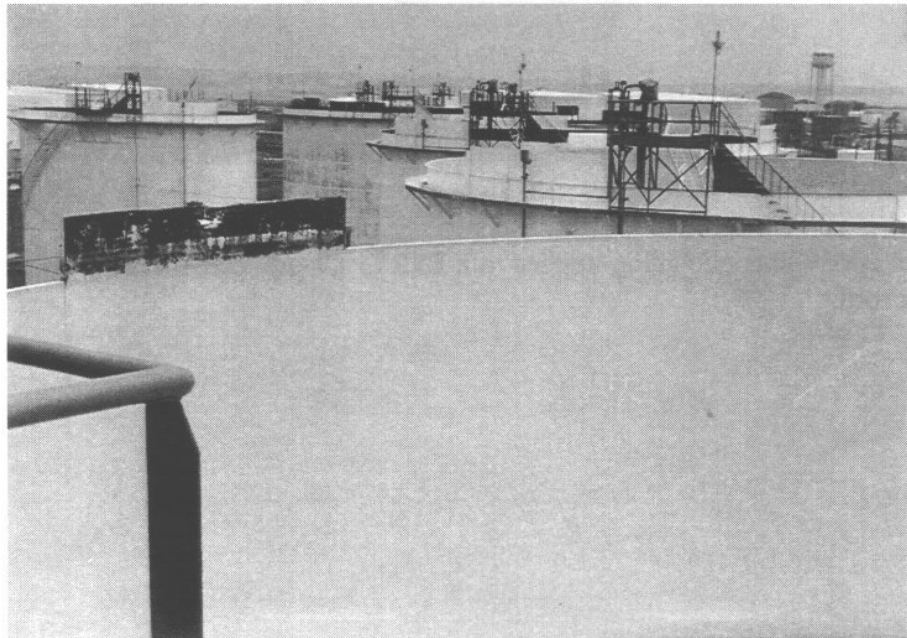


Figure 8

The shell of a floating roof tank in jet fuel service coated with an epoxy-phenolic. Note the extent of corrosion on the baffle for the foam fire fighting system. Additional lined tanks are shown in the background.

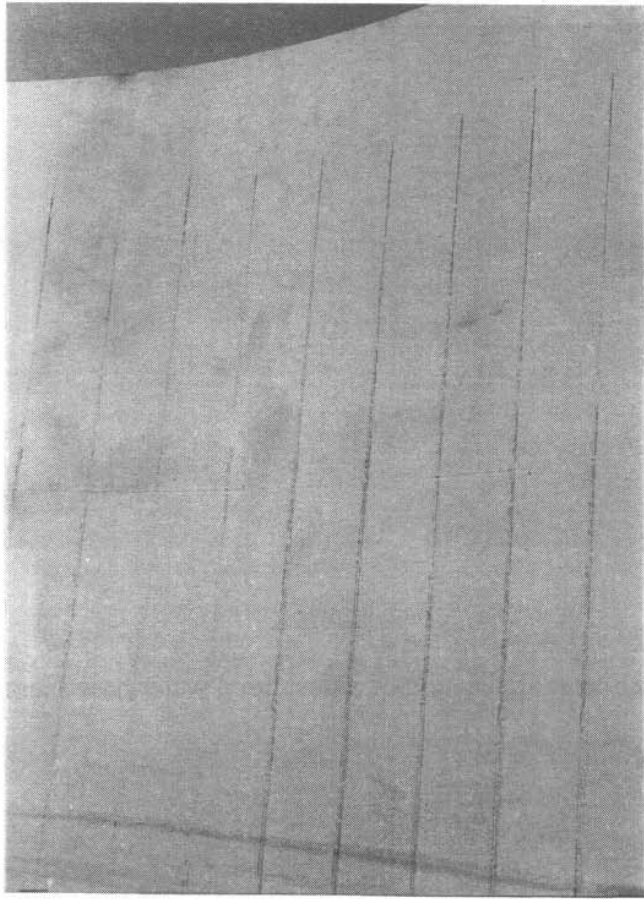


Figure 9

Another view of an epoxy-phenolic lining applied to a EFRT. Clearly evident is the abrasion caused by the seal of the floating roof.