PREDICTIVE MAINTENANCE OF FIBERGLASS REINFORCED PLASTIC EQUIPMENT

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ABSTRACT

For steel, stainless steel and titanium process equipment, reliable and valid methods are used to monitor the effects of corrosion and damage in order to determine maintenance and replacement needs. This paper describes a non-destructive technology for evaluating fiberglass reinforced plastic (FRP) equipment to achieve the same results, usually while the mill is operating and without confined space entry. The results can allow the maintenance team to predict maintenance needs and the remaining service life of equipment. The method has been shown to be reliable and valid. Case studies are presented to show how the technology has been used on FRP in a number of chemical services including chlorine dioxide.

INTRODUCTION

Fiberglass reinforced Plastic (FRP) is widely used for tanks, scrubbers, pipelines and other equipment in many industrial applications for corrosion resistance, particularly for acidic solutions, at moderate temperatures. Common applications include containment of solutions including brine, chlorine dioxide, chlorine, sodium hypochlorite and weak sulfuric acid, among many others.

FRP is commonly used throughout the chlorine dioxide and sodium hypochlorite production processes starting in the electrolysis stages, continuing through product storage to application and use. In pulp bleaching plants, FRP is also used in tanks, vessels and pipelines for pulp being bleached, washer filtrates and wastewater.

In many paper industry applications, especially involving corrosion, non destructive testing is used as part of a maintenance reliability program to evaluate the condition of equipment and identify repair needs and priorities for execution in a planned and deliberate manner. Often, non destructive condition monitoring allows repair and replacement needs and scopes to be predicted within the budget cycles of large corporations.

Traditional evaluation and condition monitoring of FRP almost always involves visual assessment of the surface and near-surface that is exposed to the corrosive conditions. The focus is generally limited to the corrosion barrier. This assessment allows some measurements and calculations of corrosion and oxidation rates and prediction of maintenance needs for the corrosion barrier. With the use of best practices and skilled inspectors, some reliability gains can result. There are some limitations of this visual inspection process: confined space entry is almost always required, equipment must usually be evaluated during outages, most pipelines cannot be inspected, very limited evaluation can be made of the structural condition of FRP and skilled inspectors are relatively rare.

This paper describes a non-destructive technology that is used successfully as part of several maintenance reliability programs for FRP.

BACKGROUND

In the early 1960's, use of ultrasonic testing (UT) was already showing reliable results for finding flaws in metallic structures. One of the desirable attributes of this technique is that reliable data could be generated if only one side of the material under investigation was accessible. This meant that in addition to finding flaws or defects, the same techniques could be used to produce thickness records of reasonable accuracy. A direct consequence was that the corrosion rate of metallic equipment could be determined and replacement could be budgeted and planned. Figure 1 shows an example corrosion curve and illustrates how replacement can be planned.

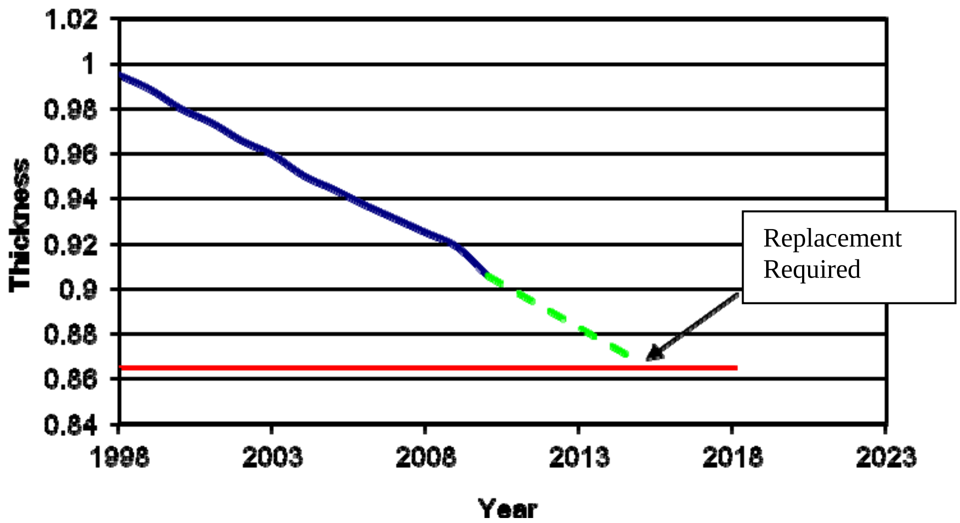

Figure 1

At the same time, use of composite materials such as FRP was being explored for a number of structural and corrosion-resistant applications. Starting in the mid 1960's, researchers started to examine uses of ultrasound with these fiber-reinforced composite materials. Consistent with the experience with metals, most work focused on finding features such as foreign objects, separation of layers, gaps and gas bubbles, thickness and damage assessment.

Also in the 1960`s, FRP and other composites were being investigated for aerospace uses. Much of the investigation of UT for FRP was started by NASA. Results of these investigations developed traditional inspection procedures for finding defects and features, generally limited to high cost, high strength aerospace composites. Additional findings from these investigations showed that composites that are stressed will also see a reduction in strength as a result of irreversible changes that have occurred. Further, investigators found that these changes can be detected through changes in acousto-ultrasonic responses of the composite[1]. Since then, research has shown that the same characteristic exists for FRP[2].

Technology development has been completed with the following objectives:

1. Develop procedures to allow the use of commercially available UT equipment;
2. Verify the results of calculations for FRP.

The results of the work are summarized below.

Commercially Available UT Equipment

Part of the process for evaluating the changes that have occurred to the UT signals as they travel through the FRP requires that calculations be done on the data received by the flaw detector equipment. Data files are stored in the equipment at the time that readings are taken and are processed after data collection.

Readings are taken with specific ultrasonic equipment, following a written procedure. UT equipment selection is partly based on the ability to extract the data files from the equipment for processing. There is currently a small list of equipment that meets the data-handling requirements for this evaluation.

Data files including the readings are extracted from the equipment after the readings are completed and further information is added about the FRP. The resulting data file is then analyzed and calculations are completed to provide the existing properties of the FRP.

The calculation output of interest for this paper is the percentage of design strength (PDS) for the FRP. The PDS multiplied by the design strength of the FRP will give the current strength.

Verification of Results

To verify the UT results, samples of FRP have been removed from various structures and tested, both by collecting ultrasonic data and by using a destructive test to determine the strength of the FRP. Most of the specimens were from cylindrical tanks and pipes where the material properties in the hoop direction were of most interest. The designation of the destructive test used is ASTM D790[3] for vessels and ASTM D2290 for pipe.

For each of the samples tested, the following procedure was followed:

1. Ultrasonic data and thickness measurements were collected from the sample.
2. The sample was cut into test specimens in accordance with ASTM D790 or D2290.
3. Where the lamination sequence of the sample was unknown, a specimen was also cut for ignition loss analysis in accordance with ASTM D2584[5] and reinforcement analysis.
4. A third-party test laboratory completed the ASTM D790, ASTM D2290 and ASTM D2584 (as applicable) testing and reported the results.
5. The 3rd party laboratory returned the reinforcement from the ASTM D2584 specimen as it was removed from the furnace.
6. The ASTM D2584 residue was used to determine the lamination sequence.
7. The original properties of the FRP were modeled using lamination analysis as described in ASME RTP-1[6].
8. The flexural modulus result obtained from the ASTM D790 test or the tensile strength from ASTM D2290 was normalized by dividing it by the design values from lamination analysis modeling. This is termed "Normalized Strength Fraction"
9. The Normalized Strength Fraction is compared to the PDS from the ultrasonic analysis.

An example of the calculation process is shown in Table 1 below:

Table 1

Design Flexural Modulus (psi)	Thickness (in)	ASTM D790 Modulus (psi)	Normalized Strength Fraction	Ultrasonic PDS
2,229,406	1.891	1,342,000	0.602	0.604

The results of the comparison are shown in figure 2. The average difference between the destructive test results and the UT calculated values is 7% of the destructive test results.

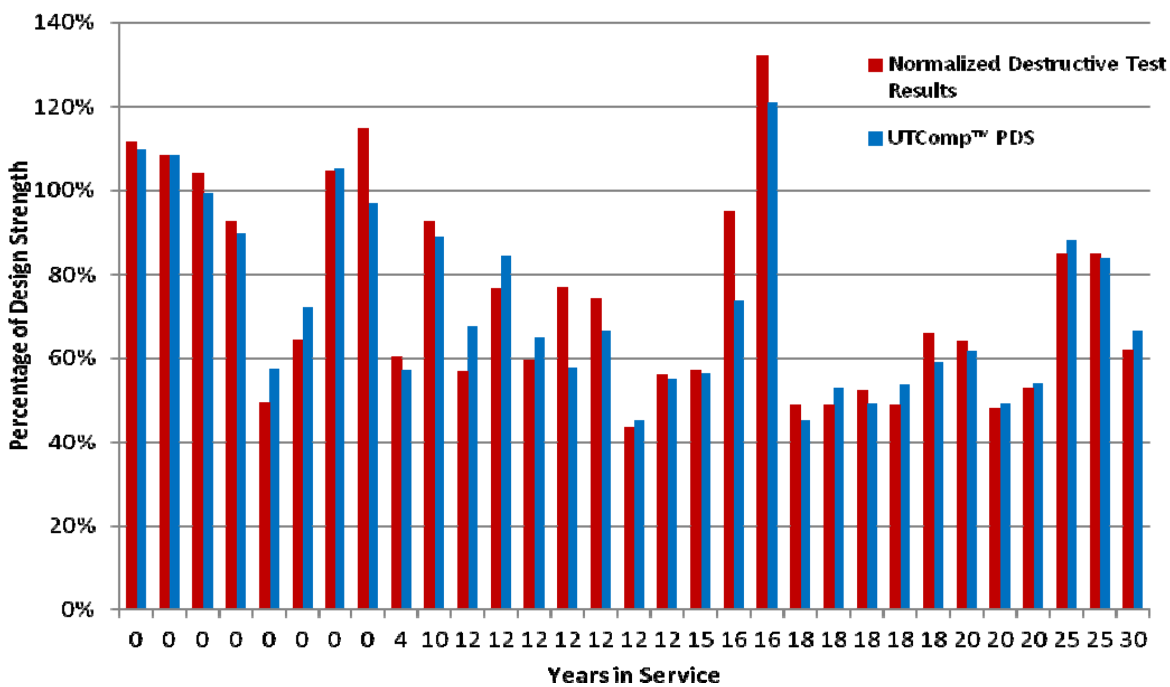

Figure 2

From these results, it is concluded that ultrasonic strength determination using commercially available UT equipment can produce reliable and valid analysis of FRP.

The data distribution is as shown in Figure 3. From this it is deduced that the accuracy of the UT results is within reasonable and known limits.

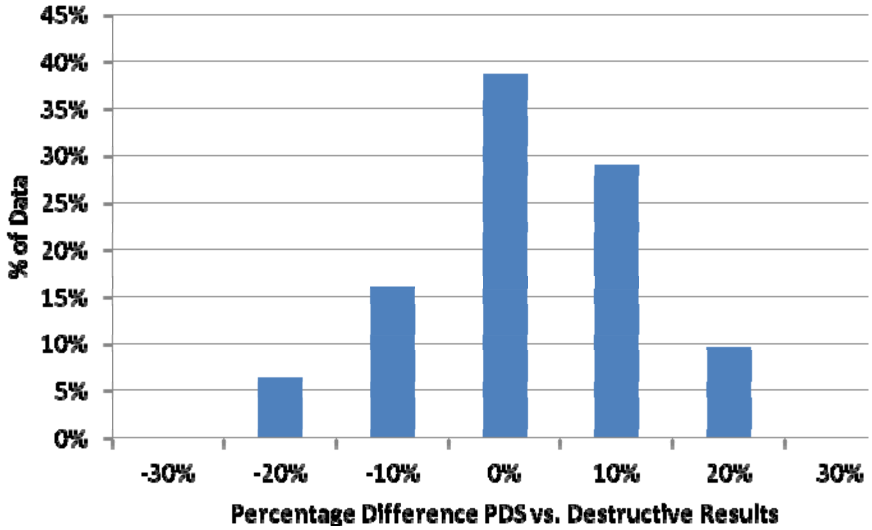

Figure 3

Other Results

While completing the validation work, several other features of the UT analysis process surfaced. These are summarized below:

1. Readings taken from the outer surface can show the condition of the inner surface, or corrosion barrier.
2. Readings can be taken from FRP equipment in operation.
3. Thickness of the corrosion barrier can be inferred.

Limitations

Use of this UT method for evaluating FRP has few limitations:

- Ambient temperatures should be above 15°C, and
- Atmosphere can be provided where a potential spark from the UT equipment does not create a hazard (it is not intrinsically safe and could provide an ignition source)

When these are limitations are respected, readings can be taken from FRP that is empty or full and pressurized or evacuated. Data can usually be obtained without taking production outages. Collecting data from equipment containing liquid usually provides additional information about the condition of the corrosion barrier.

APPLICATION OF THE TECHNOLOGY

Returning now to figure 1, where the lifetime of a metal vessel is modeled based on thickness; it is proposed that parallel results can be produced for FRP.

First consider the case where the thickness of FRP does not change appreciably over time and exposure to contents. This would apply generally for many applications. In this case, the PDS value can be determined periodically, often while the FRP equipment is in operation. The analysis can be used to produce an ongoing history of PDS values and corrosion barrier condition for common sections of the equipment.

In cases such as chlorine dioxide applications, where oxidation can reduce thickness, the analysis combines thickness and PDS to produce two results:

1. an "effective thickness" that is used in a similar manner as the PDS, and

2. the expected loss of corrosion barrier that has occurred

To maximize the value of the history, some key information is recommended. The starting point is the strength, or PDS, of the FRP when it is new. Another important item is to have criteria to identify the remaining service life, or the time that corrective action is recommended. These items are discussed below.

Starting Point - Baseline

The recommended way to monitor changes is to develop a baseline for FRP equipment when it is new, as some variability exists among all new FRP. If baselines are not available, an amalgam of data from FRP laminates from several fabricators has been used successfully. Using this "standard baseline" always assumes that the new FRP was at 100% of its design strength.

It is important to note that each set of readings is independent and the value of the starting point will not affect any data collected for the FRP. At the time of this writing, original baseline data for most FRP in use is not available. The standard baseline value has been found to generally yield conservative predictions for corrective action. As history for particular FRP develops, it is possible for the starting point to be adjusted or modified to match the data.

Remaining Service Life

The remaining service life is the time until corrective action is recommended. It is reported as the date when corrective action should be expected. In most cases remaining service life is calculated using a straight line model, similar to methods used in API 653, Tank Inspection, Repair, Alteration and Reconstruction[6.].

Reliable calculation of the remaining service life requires criteria for its calculation. The method used is;

1. Obtain some information about the equipment from nameplates or drawings to determine design safety factors, age and operating conditions. This can usually be done during the first field evaluation,
2. Determine the PDS where the Safety Factor is expected to be 2, and identify that as the Critical PDS where Corrective Action is recommended.
3. Determine the PDS where the equipment is expected to be at ¾ (75%) of its life. At this PDS, Engineering Review is recommended to verify the Critical PDS and identify potential reliability and lifespan improvements.

If very limited information is available, it is still generally possible to develop the required parameters based on experience and knowledge of FRP.

Condition Monitoring

The condition monitoring process starts with some planning for the equipment to be monitored. The plans determine what sections of the FRP are to be tested by considering information available and safe working environment.

Readings are taken from the FRP according to written procedures from equipment that is empty or full and pressurized or evacuated.

After the readings are taken, the data from the UT equipment is exported to a computer program that prepares a data file. For most equipment, several data files are usually produced at an inspection. These data files are combined for the asset into an inspection file.

The inspection file is then sent to an experienced engineer who completes the analysis using specialized computer software. Every reading is reviewed and calculations are performed. From each inspection file, a report is generated showing the results from all data files combined to present the FRP asset as a whole. This will include history and calculation of remaining service life for the equipment as a whole, while recommending corrective actions.

An example of a PDS History is shown in figure 4. This is the history for a relatively large storage tank. The trend curve shown on the graph is based on projecting a conservative trend based on the data points. This figure also includes the Engineering Review threshold and the Critical PDS threshold that have been determined using the method described above. For this figure, Engineering Review is recommended in 2015 and end of service is predicted at 2022.

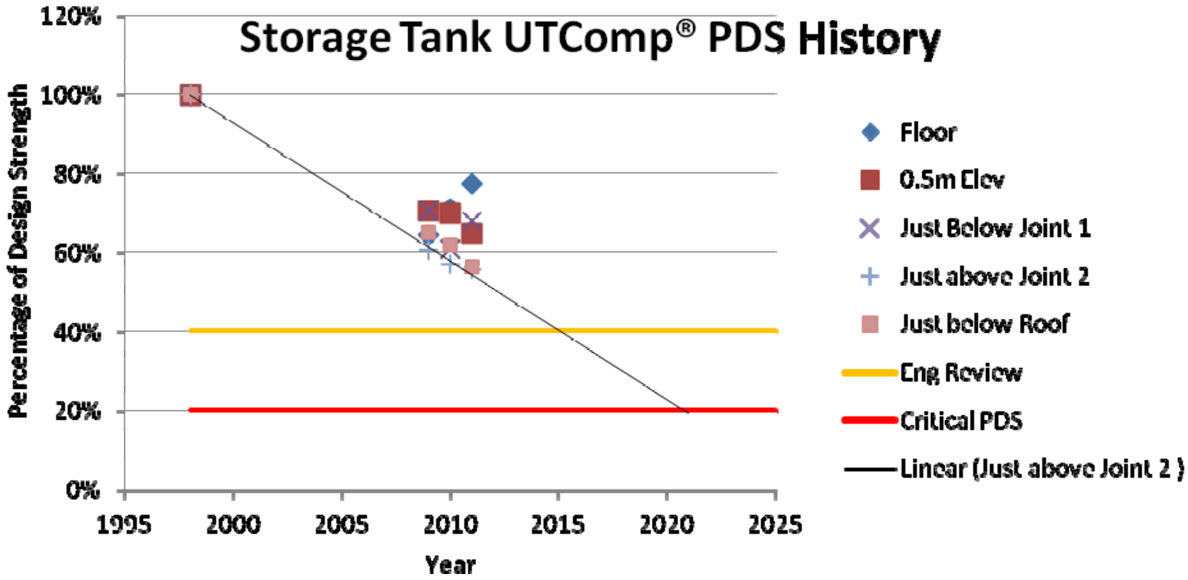

Figure 4

An example of a pipeline survey is shown in figure 5 and the corresponding remaining service life calculation is shown in figure 6. This pipe was built with a very thick, sacrificial corrosion barrier to accommodate oxidation. The original corrosion barrier thickness was 0.5inch.

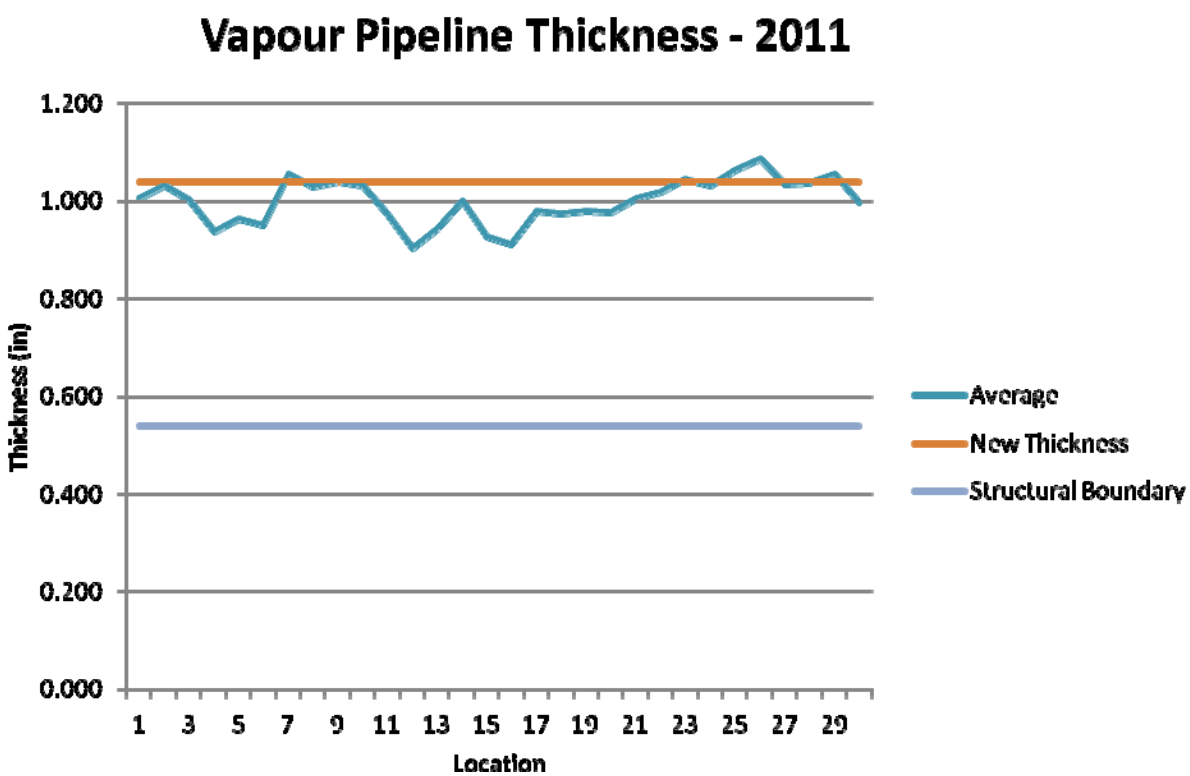

Figure 5

In Figure 6, any data shown above the “Structural Boundary” line shows that some of the corrosion barrier remains. The remaining thickness of corrosion barrier can be shown as illustrated in Figure 7.

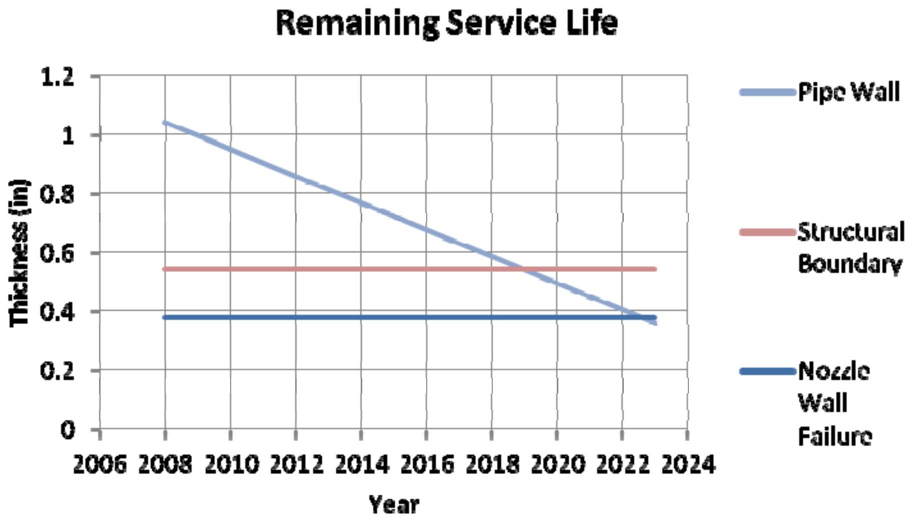

Figure 6

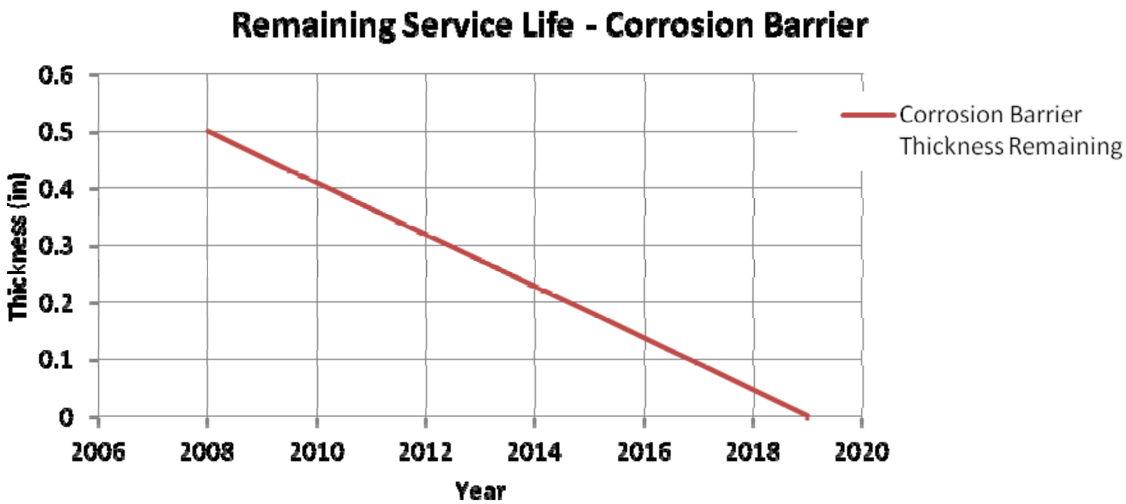

Figure 7

CASE STUDIES

To illustrate the process, two (2) case studies are presented.

Chlorine Dioxide Pipeline

This case study is a pipeline section where chlorine dioxide is mixed with pulp before a pre-retention tube. This is the first time that readings have been taken from this pipeline, so historical UT information is not available. The pipeline survey results are shown as the product of the actual thickness and the PDS value, giving the effective thickness of the pipe. Figure 10 shows the survey with the new thickness marked as a comparison. Note that the middle section of the chart shows results where the structural FRP is being oxidized. The corrosion barrier is effectively absent from this entire pipeline.

The readings from 13 to 19 are from the part of the pipeline where chlorine dioxide is mixed with the pulp. This section of pipeline has now been replaced. Most of the pipeline shown in this example has now been replaced.

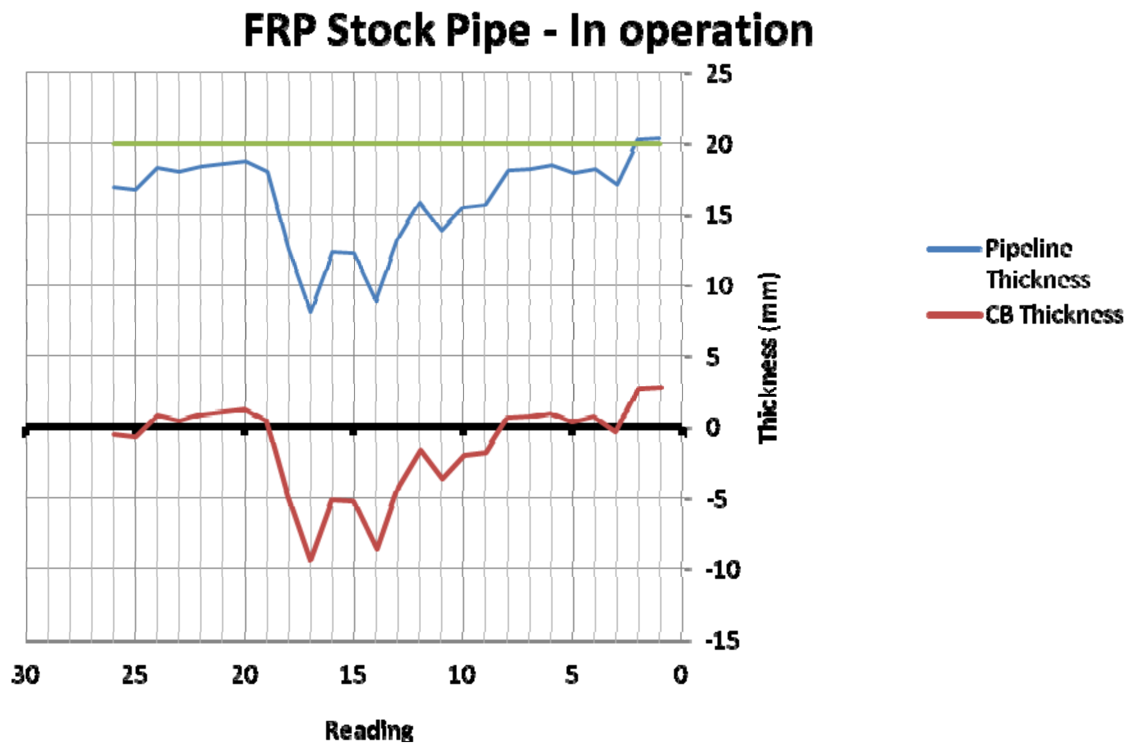

Figure 9

Repaired Tank

Figure 11 shows the history of a tank that was repaired in 2011. Engineering Review was undertaken after the readings in 2011 and it was found that the tank service had changed. Repairs were recommended to accommodate the process change. The graph shows the results of UT analysis over this period of time.

This tank continues in service.

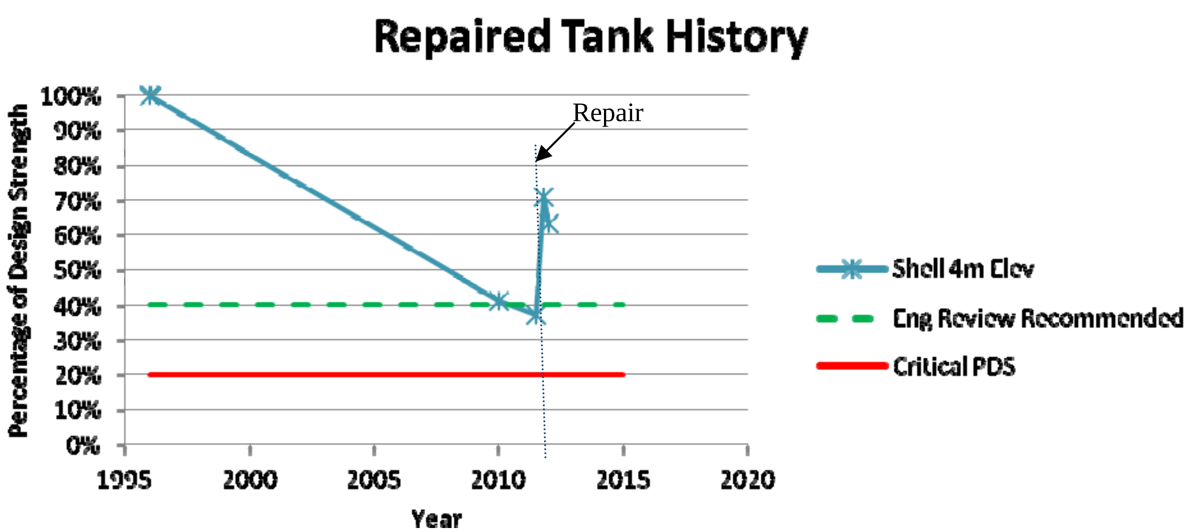

Figure 10

CONCLUSIONS

This paper illustrates an ultrasonic condition monitoring system that has been used successfully to provide reliability information for owners of FRP assets. From this paper, the following conclusions are presented:

1. FRP strength properties can be determined accurately and reliably from UT data.
2. It is possible to determine corrosion barrier condition from the opposite surface with UT.
3. FRP condition can be monitored by following changes in FRP properties.
4. UT condition monitoring has been shown to provide meaningful information for FRP reliability.
5. UT condition monitoring is reliably completed while facility is in operation
6. UT provides valuable information for End-users in a number of industries to predict remaining service life

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