Bounding the Minimum API 653 Tank Bottom Corrosion Rate

Philip Myers

17 September 2017

1 API 653 Rules for Predicting Corrosion Rate Intervals

API 653-5 specifies a non mandatory methodology for computing the tank bottom corrosion rate life for a future interval based on the previous interval and corrosion rate findings. Because of the universal industry acceptance of API 653, this method is widely used, in spite of the problems that we illustrate in this paper. We show that there are significant problems with this methodology under certain conditions. Moreover we show how a simple correction can be made to the standard or by users of the standard to reduce the potential for leaks to occur as a result of the unconservative methodology given in the standard. The API 653-5 methodology is shown in Figure 1 for convenience.

2 Notation and Meaning

Because there are many symbols a systematic approach to naming variables is taken and given in the table. This nomenclature omits the need for specifying top side or bottom side corrosion. If it is needed as, for example,

4.4.5.1 An acceptable method for calculating the minimum acceptable bottom thickness for the entire bottom or portions thereof is as follows:

$$MRT = (\text{Minimum of } RT_{bc} \text{ or } RT_{ip}) - O_r\,(StP_r + UP_r)$$

where

- MRT is the minimum remaining thickness at the end of interval O_r. This value must meet the requirements of Table 4.4 and 4.4.5.4 and 4.4.6;
- O_r is the in-service interval of operation (years to next internal inspection) not to exceed that allowed by 6.4.2;
- RT_{bc} is the minimum remaining thickness from bottom side corrosion after repairs;
- RT_{ip} is the minimum remaining thickness from internal corrosion after repairs;
- StP_r is the maximum rate of corrosion not repaired on the top side. $StP_r = 0$ for coated areas of the bottom. The expected life of the coating must equal or exceed O_r to use $StP_r = 0$;
- UP_r is the maximum rate of corrosion on the bottom side. To calculate the corrosion rate, use the minimum remaining thickness after repairs. Assume a linear rate based on the age of the tanks. $UP_r = 0$ for areas that have effective cathodic protection.

NOTE 1 For areas of a bottom that have been scanned by the magnetic flux leakage (or exclusion) process, and do not have effective cathodic protection, the thickness used for calculating UP_r must be the lesser of the MFL threshold or the minimum thickness of corrosion areas that are not repaired. The MFL threshold is defined as the minimum remaining thickness to be detected in the areas examined. This value should be predetermined by the tank owner based on the desired inspection interval.

Areas of bottom side corrosion that are repaired should be evaluated with the corrosion rate for the repaired area unless the cause of corrosion has been removed. The evaluation is done by using the corrosion rate of the repaired area for UP_r, and adding the patch plate (if used) thickness to the term "minimum of RT_{bc} or RT_{ip}."

NOTE 2 Corrosion of the bottom plate includes loss of metal from isolated or general corrosion.

4.4.5.2 For the probabilistic method, a statistical analysis is made of thickness data from measurements (see 4.4.6) projecting remaining thickness, based on sample scanning of the bottom.

Figure 1: API 653-5 Rules for the Next Operating Interval

in a computer program then subscripts 1 and 2 can be added for the top side and bottom side corrosion respectively.

Symbol	Units	Subscripted	Definition
A	yr	na	previous interval or age
MRT	mils	na	min remaining thickness
RT0	mils	na	nominal thickness or previous interval thickness
RTb	mils	RTb1, RTb2	remaining thickness before repairs
RTa	mils	RTa1, RTa1	remaining thickness after repairs
D	mils	D1,D2	max depth of corrosion
C	mpy	C1,C2	linear corrosion rate
C6	mpy	C61,C62	API 653 corrosion rate
Cb	mpy	Cb1,Cb2	bounded corrosion rate
O6	yr	O61, O62	next API 653 interval
Ob	yr	Oh1, Oh2	corrosion rate bounded interval
α	na	$\alpha 1$,$\alpha 2$	see figure

Figure 2 shows what the symbols mean.

A word about RT0 is in order. If we are considering the first inspection after the new bottom has been in service the RT0 is the bottom plate nominal thickness. If we are consider several inspection into the bottom life cycle, then RT0 is the minimum of remaining thicknesses after repairs (i.e. RTa1, RTa2) from either top side or bottom side corrosion.

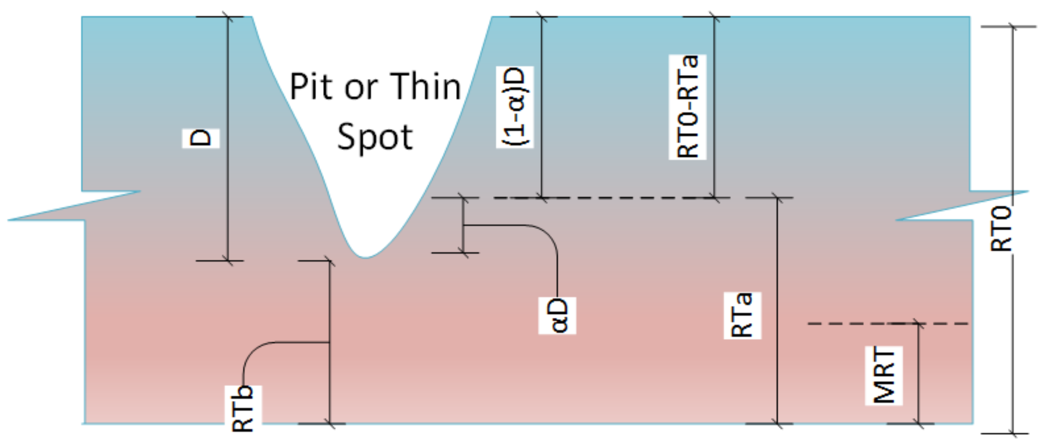

Figure 2: 1 Important Symbols

3 Physical Interpretations

Recall that the the slope of time in service against a corrosion depth is the definition of a corrosion rate. That is, the depth of corrosion D divided by the time in service A is the slope of the corrosion rate line. We show with some figures what is actually occurring. Let us assume that the linear corrosion rate model is in fact true. In figure 3 we show the true linear corrosion rate as the bottom line C. The corrosion starts at time 0 (i.e. new bottom or repaired bottom at thickness RT0) and when inspected some years later at the inspection point shown by the vertical line, the deepest corrosion is measured. This determines the linear corrosion rate indicated by the bottom most line. Because the tank bottom will be repaired to RTa, another line with the same slope is created at the intersection of the inspection point and with thickness RTa. Using the same slope projects down to the red cross which is the time to penetration of the tank bottom assuming the linear rate determined by the previous interval starts at the new interval (at the inspection point) and continues until tank bottom penetration. The upper line is C6 which is the corrosion rate computed according to the API 653 methodology.

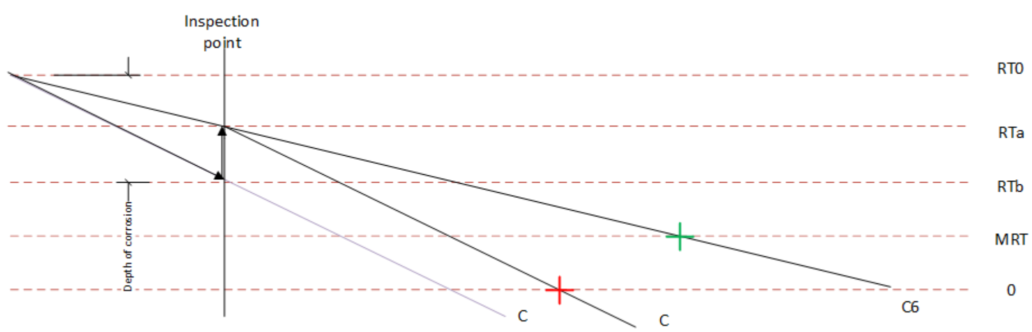

Figure 3: 1 Negative of line slope is corrosion rate

The slope of the API corrosion rate is not fixed but is dependent on the repair to thickness RTa which is arbitrary. This is illustrated in Figure 4 where any of the solid black lines can be the API 653 corrosion rate depending on the value of RTa. Notice that the API 653 corrosion rate C6 is always less than or equal to the value of the linear corrosion rate C.

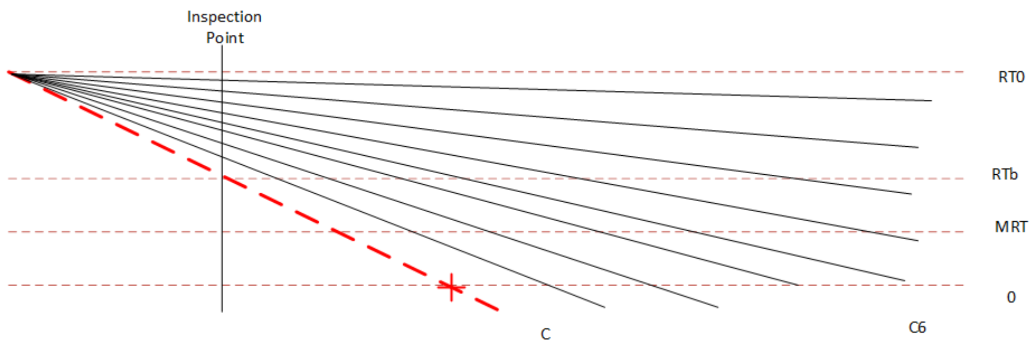

Figure 4: 1 Multiple API 653 Corrosion Rates Depend on RTa

In Figure 5 we show how the API corrosion rate can be conservative and unconservative depending on the values of RTa and RTb. The derivations for the bounded corrosion rate methodology are shown later. In Panel 1 the API 653 criteria are acceptable because a bottom penetration does not occur. Note that RTa was at or slightly greater than RTb. In panel 2, we increase the difference between RTa and RTb and the API 653 criteria are still acceptable. In Panel 3 the difference between RTa and RTb is such that the bounded corrosion rate life is just equal to the API 653 corrosion rate life. (This paper provides the methodology for computing this rate.) Finally, in Panel 4, we see that the API 653 corrosion rate is unacceptable because the bottom has been penetrated by corrosion prior to the computed API 653 interval.

4 Derivations Needed

In this section we derive the bounded corrosion rate below which the API 653 calculation should not be allowed to fall which would result in a possible hole in the tank bottom based on the discussion in the previous section.

4.1 Basic Relations

The linear model corrosion rate is determined by

$$C = \frac{D}{A} \tag{1}$$

whereas the API 653 "corrosion rate" is

$$C6 = \frac{RT0 - RTa}{A} \tag{2}$$

and the corrosion rate ratio is

$$\frac{C6}{C} = \frac{RT0 - RTa}{D} \tag{3}$$

4.2 Comparing Predicted Intervals Under the API and Linear Models

Let O be the predicted next operating interval until the linear corrosion rate just penetrates the bottom. Then, the predicted API 653, the linear corrosion intervals, and the ratio of intervals are

$$Oh = \frac{RTa}{C} \tag{4}$$

$$O6 = \frac{RTa - MRT}{C6} \tag{5}$$

$$\frac{O6}{O} = \frac{RTa - MRT}{C6} \cdot \frac{C}{RTa} \tag{6}$$

$$= \left(1 - \frac{MRT}{RTa}\right) \cdot \frac{C}{C6} \tag{7}$$

4.3 Preventing the API Model Corrosion Rate Being Too Low

To make the point about serious problems with the API 653 methodology, let's assume that the repair-to thickness is 250 mils. This results in a corrosion rate of 0 and an infinite interval. We know this is not possible. The procedure of this white paper is to propose a very simple fix to the existing API 653 rules which will prevent prematurely failed tank bottoms.

In order that the corrosion under the linear assumption not penetrate the bottom we must have the ratio $\frac{O6}{O} \leq 1$ so that from (6) and (7)

$$\left(1 - \frac{MRT}{RTa}\right) \cdot \frac{C}{C6} \leq 1$$

Rearranging, provides criteria to ensure that the corrosion rate computed by API 653 is sufficiently high to prevent penetration

$$C6 \geq \left(1 - \frac{MRT}{RTa}\right) \cdot C$$

This is accomplished by restricting the minimum API 653 corrosion rate value or bounding the corrosion rate Cb computed under the API 653 rules to be no less than

$$Cb = \left(1 - \frac{MRT}{RTa}\right) \cdot C \tag{8}$$

In other words, the corrosion rate computed by API 653 must never fall below the bounded rate:

$$C6 \geq Cb \tag{9}$$

5 Some Plots

In Figure 7 the API 653 interval is computed with bounding line. Note that the API 653 rate is independent of the linear corrosion rate determined from the previous operating interval and remains constant at 40 years. However, above 5 mpy, the 40 year interval is too long a a hole will develop. This plot is based on the data from Example 1.

If we increase the API 653 corrosion rate by then Figure **??** shows that when the linear corrosion rate exceeds 10 mpy we must bound it.

6 Some Practical Considerations

6.1 The Value of the Corrosion Rate Bound

Assume that we have a tank constructed with 250 mil nominal bottom thickness plates. For a corroded topside tank bottom surface, the repairs are often done by filling pits with welds or by replacing or patching with new plate. It should be easy to see that the repair-to thickness for the top surface must be limit to some value well below 250 mils otherwise the entire bottom would have to be replaced. From a practical perspective, the repair-to thickness is boing to be in a range from 180 to 220 mils. The lower the repair-to thickness the less the repair costs but the shorter the next interval is. Similar concepts apply to the bottom repair-to thickness.

In considering Eq 8 we the ratio of MRT/RTa is going to be roughly in the range [0.55, 0.45] based on the range of repair-to thicknesses. Then, the bounding factor $1 - MRT/RTa$ will have values in the range [0.45, 0.55]. This means that the lower bound below which the computed API 653 corrosion rate must not fall is about 1/2 of the linear corrosion rate.

6.2 A Few Examples

An excel calculator is available from PEMY to quickly produce the types of calculations discussed in this paper. Note that for the purpose of clarity we will ignore the basic inspection limits such as 20 years and consider only the corrosion rate lives.

In Example 1 (see Figure 8) a sample calculation compares the API 653 interval calculation to that of the bounded corrosion rate calculation. The first group of numbers (1-5) are inputs. The original thickness is 250 mils, the previous service time 20 years, the planned repair-to thickness is 200 mils, a minimum remaining thickness of 100 mils, and the deepest top side corrosion of 50 mils.

In Table 1 notice that the API 653 interval (11) is 40 years for both the API 653 algorithm and the API 653 bounded corrosion rate model (12).

There is no difference between the methods and they agree. This is not the case for Example 2

In Example 2 (see Figure 9) we change the deepest corrosion to 175 mils (5) and the corresponding previous interval corrosion rate goes up to 8.75 mpy (7). Notice how line (11) now differs from line (12). The interval is decreased from 40 years using the API 653 method to 22.86 years (12) using the Bounded Corrosion Rate Method. This is of course driven by the bounded corrosion rate which can be no less than 4.38 mpy (11) as opposed to the API corrosion rate 2.5 mpy (8) which is unconservative and would lead to a hole in the tank bottom.

7 Corrosion on Both Top and Bottom Surfaces of Tank Bottom

7.1 Simplest Approach

The simultaneous corrosion of both top and bottom surfaces reduces the corrosion rate life or interval. However, the API 653 methodology (4.4.5.1 shown above) cannot be justified (9). The API 653 formula for simultaneous corrosion is given by

$$Or = \frac{\min(RTip, RTbc) - MRT}{(StPr + UPr)} \tag{10}$$

In the top of (9) the assumption is that the minimum remaining thicknesses from corrosion does not line up, yet the bottom of (9) assumes that they do line up. By "line up" we mean that the deepest top surface corrosion occurs at the same location as the deepest bottom surface corrosion. Regardless, for determining the API 653 interval we shall use what is prescribed.

In the proposed method for dealing with corrosion on the top and bottom we simply take the minimum of the bounded corrosion rate life computed from the methods above.

Required API 653 Interval = $\min(Ob1, Ob2)$

Here Ob1 and Ob2 are the top and bottom bounded API 653 intervals according to the procedures described above.

The spreadsheet available from PEMY's website has a calculator the computes combined top side and bottom side corrosion.

8 Recommendations

The Bounded Corrosion Rate method is a simply way to preserve most of the current methodology in API 653 without a wholesale re-write of the provisions currently used. However, it does require a few extra steps to ensure that the corrosion rate computed by API 653 is never able to become so low as to cause the inspection interval to be shorter than the hole-thru interval.

This methodology is based on the well established method of estimating corrosion rates using linearity of the corrosion rate process. Because there is little data publically available to support doing anything more than what has been proposed here, this methodology is appropriate to accept into the next edition of API 653.

The only other modification that the authors of API 653 may wish to make is to consider whether or not corrosion lines up. By this we mean that the deepest top side corrosion is exactly aligned with the deepest bottom side corrosion. Because the probabilities of this are so low they could be omitted unless the inspector has strong reasons to suspect that the opposite. In this case the inspector should have the call on summing corrosion rates as needed.

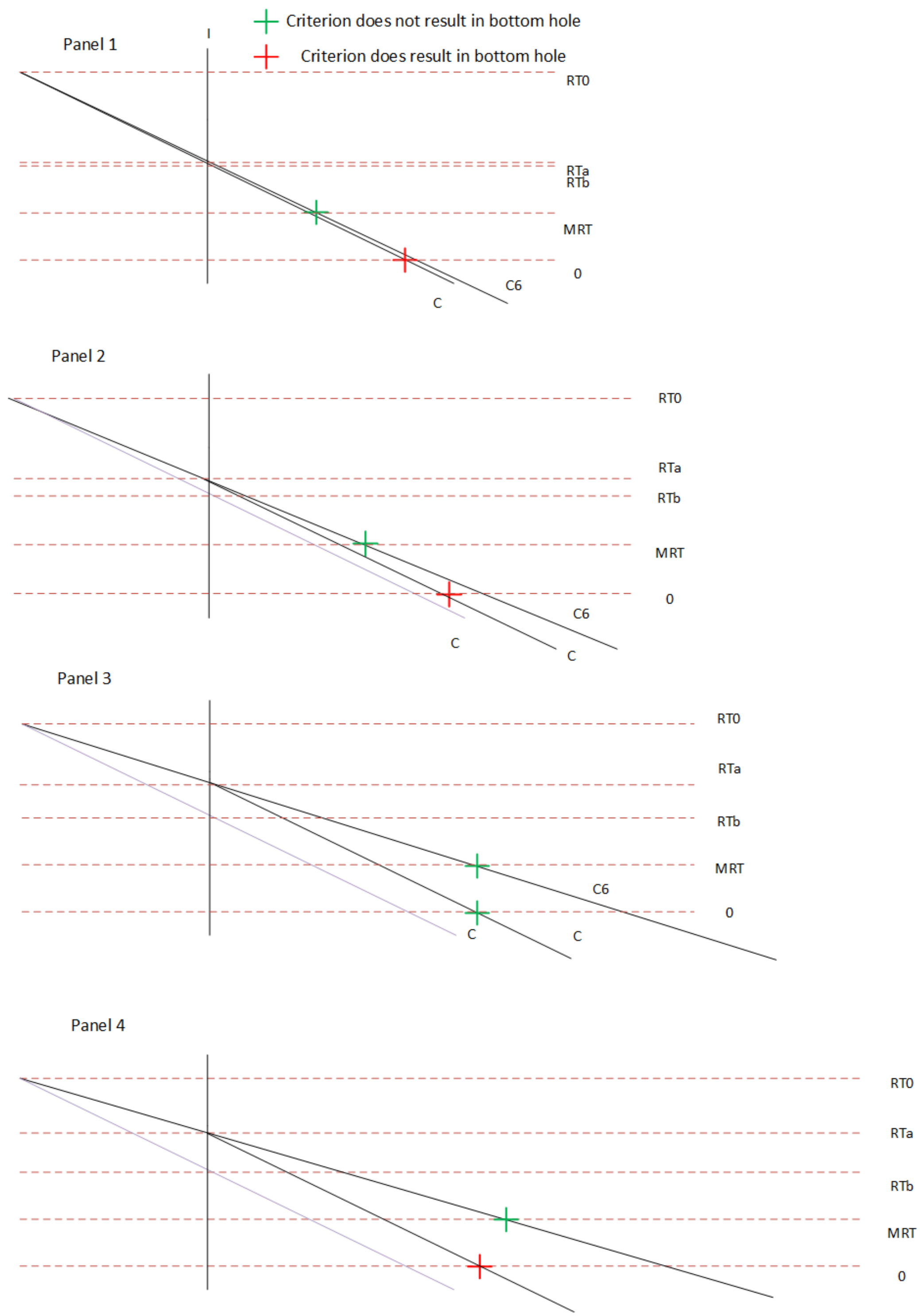

Figure 5: 1 Conservative Choices

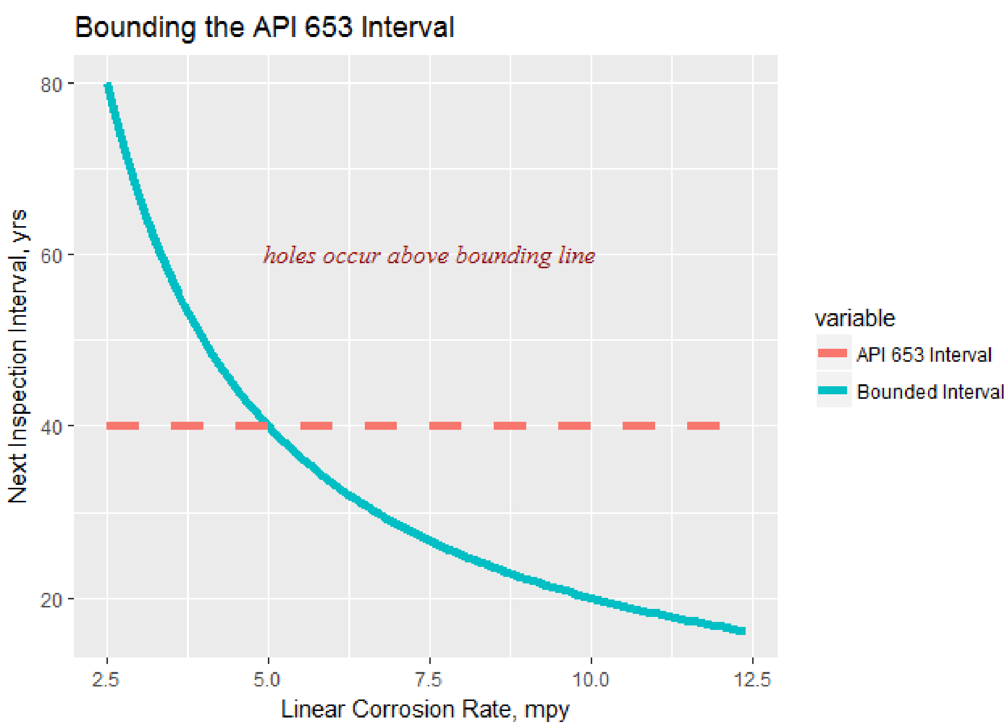

Figure 6: API and Bounding Corrosion Rate

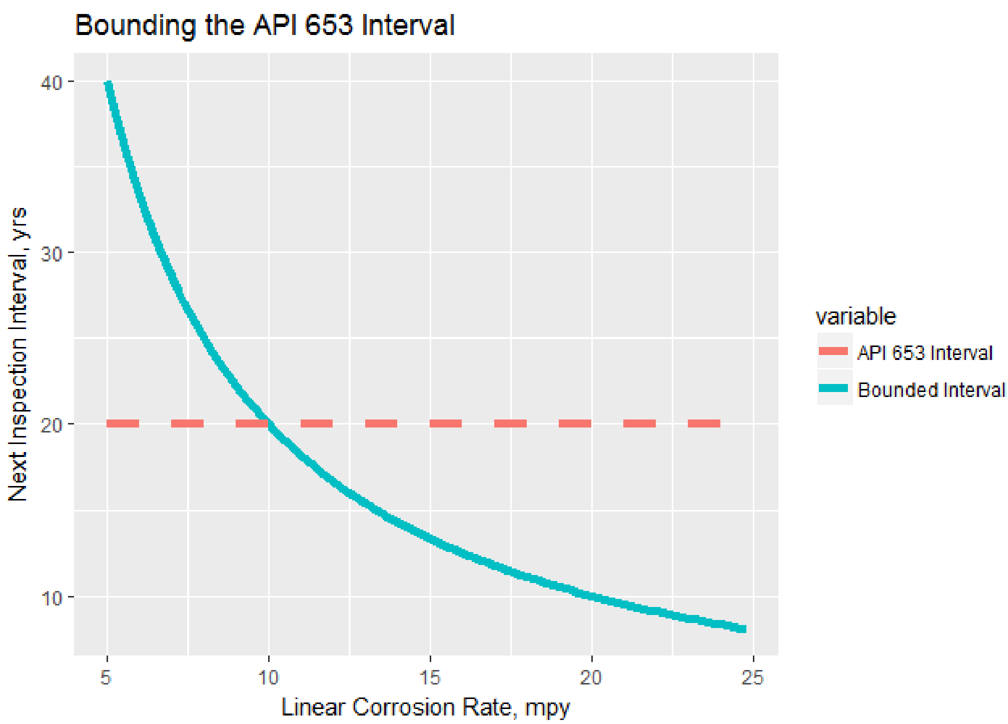

Figure 7: API and Bounding Corrosion Rate

Corrosion on One Side Only (top or bottom)				
Line	**Input data**			
1	Previous interval thickness	RT0	mils	250
2	Time in service	A	yrs	20
3	Repair-to thickness (min remaining thickness after repairs)	RTa	mils	200
4	Minimum remaining thickness	MRT	mils	100
5	Deepest internal corrosion	D	mils	50
	Corrosion rate comparisons			
6	Remaining thickness from internal corrosion (before repairs)	RTb	mils	200
7	Linear corrosion rate	C	mpy	2.5
8	API 653 corrosion rate	C6	mpy	2.5
	Corrosion Rate Bounding Calculations			
9	Bounding factor	Bf	na	0.50
10	Lower bound on corrosion rate for no hole thru	Cb	mpy	1.25
	Interval comparisons			
11	API 653 Interval	O6	yrs	40.00
12	Bounded API 653 Interval	Ob	yrs	40.00

Figure 8: Example 1

Corrosion on One Side Only (top or bottom)				
Line	**Input data**			
1	Previous interval thickness	RT0	mils	250
2	Time in service	A	yrs	20
3	Repair-to thickness (min remaining thickness after repairs)	RTa	mils	200
4	Minimum remaining thickness	MRT	mils	100
5	Deepest internal corrosion	D	mils	175
	Corrosion rate comparisons			
6	Remaining thickness from internal corrosion (before repairs)	RTb	mils	75
7	Linear corrosion rate	C	mpy	8.75
8	API 653 corrosion rate	C6	mpy	2.5
	Corrosion Rate Bounding Calculations			
9	Bounding factor	Bf	na	0.50
10	Lower bound on corrosion rate for no hole thru	Cb	mpy	4.38
	Interval comparisons			
11	API 653 Interval	O6	yrs	40.00
12	Bounded API 653 Interval	Ob	yrs	22.86

Figure 9: Example 2