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Monitoring Effectiveness of Vapor Corrosion Inhibitors for Tank Bottom Corrosion Using Electrical Resistance Probes and Coupons

Pavan K. Shukla
Savannah River National Laboratory®
Aiken, South Carolina, 29808
USA

Len J. Krissa
Enbridge Pipelines Inc.
10201 Jasper Ave NW
Edmonton, Alberta, T5J 3N7
Canada

Jerry DeWitt
Enbridge Energy Partners
222 US Highway 41, Suite 100,
Schererville, IN 46375
USA

Tim Whited
MESA
4445 S. 74th E. Ave.
Tulsa, Oklahoma 74145
USA

ABSTRACT

Electrical Resistance (ER) based probes are sometimes used to monitor corrosion of the aboveground storage tanks (AST) bottoms' underside. Prevention of soil-side corrosion of the bottom plates of aboveground crude oil storage tanks is a major challenge in the oil and gas industry. Monitoring an AST bottom corrosion and VCI effectiveness is an important factor in determining the bottom plate corrosion rate, and in taking preventive action such as application of vapor corrosion inhibitors (VCIs). ER probes are based on the bulk resistance measurements; change in element resistance data over a given period is converted to corrosion rates. ER-measured corrosion rate is an average value representing the combined effects of general, pitting, and microbiological induced corrosion. A study was conducted to rigorously compare the ER probe measurements with the corrosion observed on mass-loss coupons. ER probes were placed in a corrosive sand environment along with the mass-loss coupons which experienced both general and pitting corrosion. The coupons were removed after several months, and ER probe data were continuously recorded over the test duration. The coupons were scanned to measure metal depth versus position data which were analyzed to estimate the corrosion rate distribution. In parallel, the ER probe data were also analyzed to estimate corrosion rates. The two data sets were compared to identify similarities and delineate differences between the ER probes and mass-loss coupons. This analysis was used to determine suitability of using the ER probes for monitoring the tank bottom corrosion and VCIs' effectiveness.

Key words: Vapor Corrosion Inhibitors, Aboveground Storage Tanks, Electrical Resistance Probes, Mass-Loss Coupons.

INTRODUCTION

Literature information[1,2,3] suggest that soil-side corrosion could occur at elevated rates and cathodic protection (CP) alone may be insufficient for mitigation. This is because CP could partially or completely go out of service or CP may not reach all areas of the bottom plate. A study[4] was conducted to independently evaluate corrosion mitigation performance of Vapor Corrosion Inhibitors (VCIs) for soil-side of Aboveground Storage Tank (AST) bottom plate. The study[4] was sponsored and supported by an industry consortium of various tank operators, engineering service providers to the tank operators, and other related organizations. The study also looked at suitability of using ER probes for corrosion monitoring of the tank bottom; this paper is developed from the study report[4] and describes the work on evaluating suitability of ER probes for monitoring tank bottom plate corrosion.

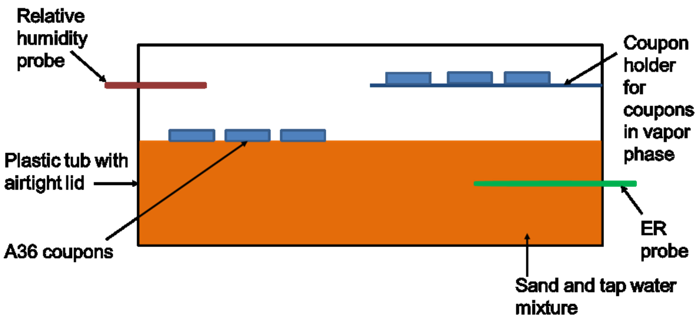
Electrical resistance (ER) based corrosion monitoring probes are sometimes used to monitor soil-side corrosion of ASTs. ER probes are inserted in to a sand pad, and the probes' metal loss data are periodically recorded which in turn are converted to corrosion rates using the elapsed time and appropriate conversion factor. Lyublinski et al.[1] and Whited et al.[3] used the ER probe to report effectiveness of VCIs, however, a correlation between the actual corrosion rate at the tank bottom and ER probe data has not been established in the literature. There is an implicit assumption that ER probe data is representative of corrosion of tank bottoms with and without VCI application. In other words, ER-measured corrosion rates are equivalent to the corrosion rates of the tank bottom plate with or without VCI dosing. To test the assumption, ER probes along with coupons were exposed to a sand electrolyte procured from a field site. The sand samples were procured form an out of service tank where severe corrosion was observed. Several corrosion experiments were setup, and ER probes along with the mass loss coupons were placed in the experiments. ER probe and coupon data were analyzed and compared. Experimental details and data and results are provided next.

EXPERIMENTAL

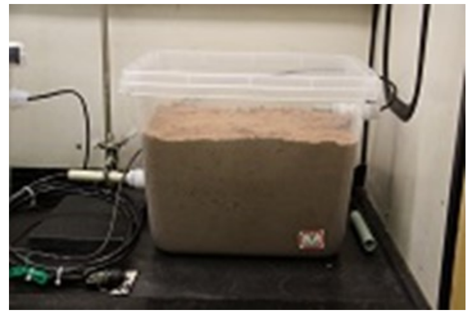
Two commercially available VCIs were tested, and are identified as VCI-A and VCI-B hereafter. Three experiments were setup in separate plastic tubs using field sand samples procured form an out of service tank. The tank bottom plate at the sand sampling site experienced severe soil-side pitting corrosion, therefore, the field sand samples were considered corrosive. The tubs were filled with the field sand, dosed with mixture of potable water plus VCIs, and sealed to avoid escaping of the VCIs. A36 grade carbon steel coupons were placed in contact with sand, and in the vapor space of the tubs.

The main difference between the three experiments was how the sand was treated. The experiment setup using the field sand without VCI is identified as sand-only. Similarly, experiment setup where field sand was treated with 100% recommended dosage of VCI-A is identified as sand + 100% VCI-A, and so on. ER probes were inserted through ports in the three experiments and included (i) sand only, (ii) sand + 100% VCI-A, and (iii) sand + 100% VCI-B. VCIs were dosed in experiments (ii) and (iii) by mixing them with potable water. The same amount of potable water was also added in sand-only experiment as in experiments (ii) and (iii). ER probes were inserted through ports in three experiments as depicted in Figure 1(a) and shown in Figure 1(b). ER probe data were collected routinely, processed, and compared to the coupon corrosion rates.

Each experiment had 12 coupons, six in contact with sand and the remaining six in the vapor space of each tub. The coupons in contact with the sand were pressed sufficiently to establish intimate contact between the tub sand and coupons. Placement of the coupons and insertion of the ER probe in each experiment mimic field situation, i.e., an AST bottom plate in contact with the sand pad as coupon in the experiment, while insertion of ER probe through ring wall ports in an AST sand pad akin to placement of the ER probes in the three experiments. Coupons were extracted from the experiments and analyzed using a laser profilometer method. Half of the coupons were extracted after 6 months of exposure and the remaining after 12 months. The coupon data were used to estimate surface average and pitting corrosion rates. The ER probe and coupon corrosion rate data were compared and to establish suitability of monitoring tank bottom plate corrosion using ER probes.



(a)



(b)

Figure 1. (a) Schematic of a tub experiment depicting position of ER probes and coupons. (b) Image of an experimental setup.

EXPERIMENTAL DATA AND RESULTS

ER probe data fluctuated daily; but showed an increasing trend over a weekly and monthly basis. Data were collected as often as possible, but didn't include data points on off-work days. Considering the fluctuations and data gaps, the data were analyzed to estimate the corrosion rates using 30-, 22-, and 11-day trends in the data. It is noted that a ER probe records 'cumulative' metal loss which is then converted to corrosion rate using exposure time and a conversion factor specific to the probe element. The estimated corrosion rates for the sand-only electrolyte, are presented in Figure 2. The 30-, 22-day, and 11-day corrosion rates are presented in Figure 2(a), Figure 2(b), and Figure 2(c), respectively. In addition, three period rolling average (defined as average of three consecutive corrosion rates), 6-month coupon, and 12-month coupon corrosion rates (average of surface averages) are also overlaid on the 30-, 22- and 11-day corrosion rates. It is observed that the rolling averages of the ER probe data tend to dampen ER data fluctuation effects.

Values of the surface average and pitting corrosion rates for the coupons were obtained by surface profiling of each coupon using a laser profilometer. The surface profile data was used to estimate corroded volume which in turn was used to estimate surface average corrosion rate. In addition, the surface profile data for each coupon also measured deepest pit depth which was used to estimate the pitting corrosion rate. Table 1 lists the coupon corrosion rates for sand, sand + 100% VCI-A, and sand + 100% VCI-B. Four additional experiments were conducted with 10 and 1% of the recommended VCIs' dosages, but no ER probes were inserted in the four experiments. Table 2 lists the coupon corrosion rates for sand-only, sand + 10% VCI-A, sand + 10% VCI-B, and Table 3 lists the corrosion rates for sand-only, sand + 1% VCI-A, sand + 1% VCI-B.

In Figures 2(a)-2(c), the initial corrosion rates derived using the ER probe data are higher than the coupon corrosion rates, however, the ER probe corrosion rates trend downward and fall in the range of the 6- and 12-month coupon corrosion rates after approximately 4-5 months. In Figure 2(a) and 2(b), the three period rolling averages of the corrosion rates are higher than the 30- and 22-day corrosion rates. However, for the 11-day corrosion rates in Figure 2(c), the three period rolling averages are nearly identical to the 11-day ER corrosion rates. The ER probe corrosion rate data in Figure 2(a)-2(c) are within the coupons' average of surface average corrosion rate range, but with a 4-5 month lag. This indicated that the ER probe can adequately monitor the corrosion rate of a AST bottom plate in the sand-only electrolyte, but a time-lag may exist between tank plate and ER-probe corrosion rates. The analysis also indicated that 11-day corrosion rate data and the rolling average of the 11-day corrosion rate tend to minimize the effect of fluctuations in the ER probe data for the sand-only electrolyte.

The ER probe corrosion rate data for the VCI dosed sand beds are presented in Figures 3 and 4. For the sand plus 100% VCI-A, 30-day, 22-day, and 11-day corrosion rates are presented in Figure 3(a), 3(b), and 3(c), respectively. In addition, the three-period rolling average of the ER-probe derived, 6-month coupon, and 12-month coupon corrosion rates (average of surface average) are also overlaid. The initial ER probe corrosion rates are lower than the coupons' corrosion rate, but the ER probe corrosion rates trend upward and come in the range of coupons' data after approximately 4 months in Figures 3(a) and 3(b). However, in Figure 3(c), the initial ER probe corrosion rates are within the coupon data, but then fall out of range for approximately 3.5 months, and then come back in the range after approximately 4 months. Overall, the ER probe corrosion rates are within the coupon corrosion rate range after some initial differences between the two. This observation is consistent with the sand-only ER probe data in Figures 2(a)-2(c). In addition, the ER probe is also able to monitor difference in electrolyte condition by way of corrosion rate measurements. For example, the coupon surface average corrosion rate decreased in the sand plus 100% VCI-A electrolyte compared to the sand-only case, and the decrease is reflected in the ER probe data.

For the sand plus 100% VCI-B electrolyte, the 30-, 22-, and 11-day ER-probe derived corrosion rates are presented in Figure (a), Figure (b), and Figure (c), respectively. In addition, three period rolling average of the ER, 6-month coupon, and 12-month coupon corrosion rates (average of surface average) are also overlaid. In this case, the ER probe corrosion rates are above the coupon corrosion rate data in Figures 4(a)-4(c); the 11-day ER-probe corrosion rate data are closest to the coupon corrosion rate data as seen in Figure 4(c). This indicates that multiple analyses of the ER probe data could provide different results, and one of those results may be closer to actual tank bottom plate corrosion rate compared to the rest.

Table 1. Corrosion rates for sand-contact coupons in sand and sand + 100% VCI

Corrosion Type	Corrosion Rate (mil/yr)*					
	Sand Only		Sand + 100% VCI-A		Sand + 100% VCI-B	
	6-month coupons	12-month coupons	6-month coupons	12-month coupons	6-month coupons	12-month coupons
Overall Surface Average	1.65	0.95	0.16	0.56	0.47	0.53
	1.90	1.14	0.74	0.53	1.63	0.47
	2.16	1.09	0.51	0.50	0.62	0.52
	Average**	**1.48**	**Average****	**0.50**	**Average****	**0.71**
	± std***	**± 0.49**	**± std*****	**± 0.19**	**± std*****	**± 0.46**
Pitting (maximum)	12.5	7.0	2.0	4.5	7.8	5.3
	9.7	13.3	3.7	5.3	11.4	3.7
	24.6	11.4	2.9	3.9	9.1	3.9
	Average**	**13.08**	**Average****	**3.72**	**Average****	**6.87**
	± std***	**± 6.07**	**± std*****	**± 1.16**	**± std*****	**± 3.09**

*1 mil/yr = 25 μm/yr
**Average values are calculated for 6 coupons for each electrolyte and corrosion type combination
***std denotes standard deviation of the data used to estimate average value

Table 2. Corrosion rates for sand-contact coupons in sand and sand + 10% VCI

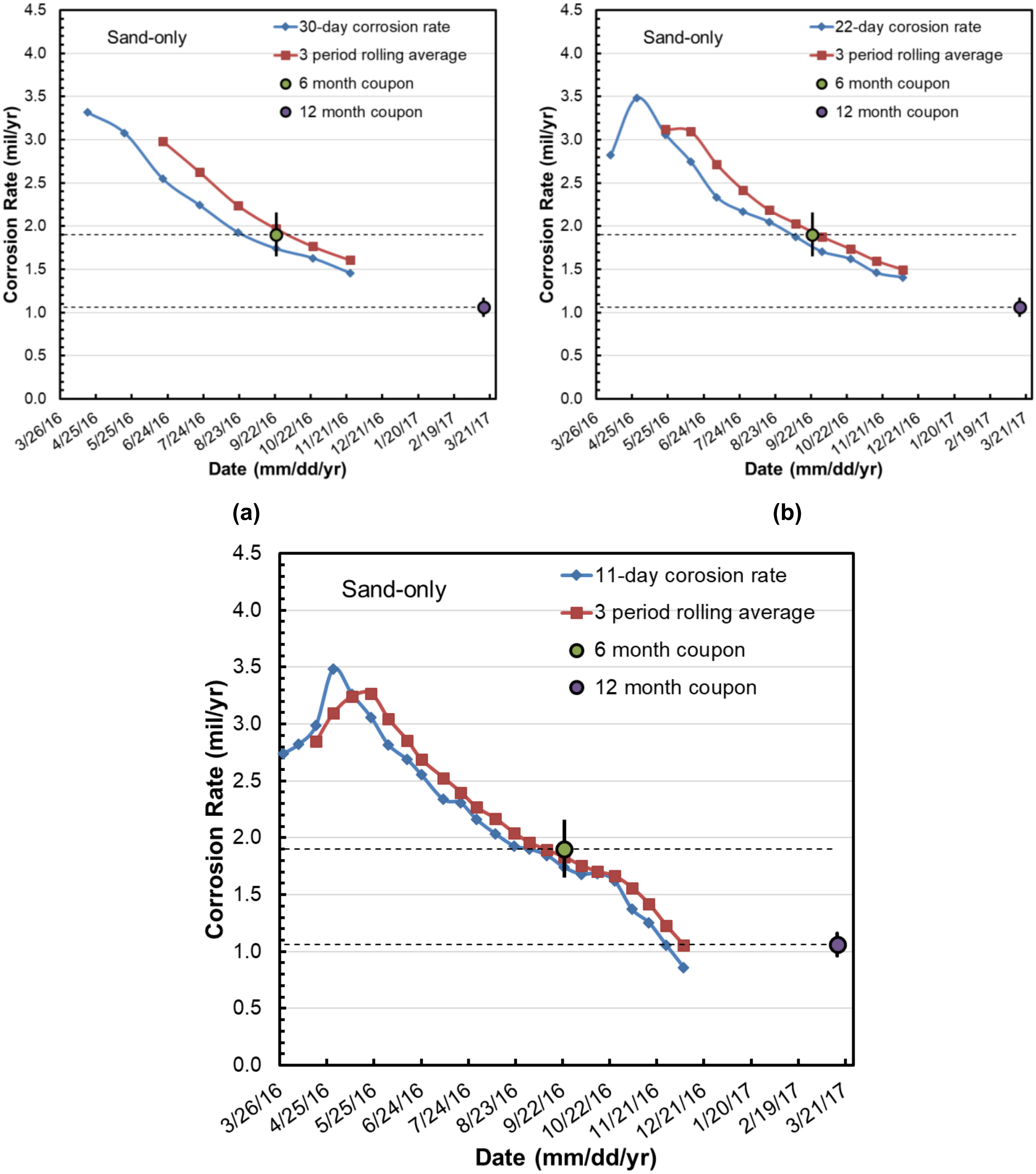
Corrosion Type	Corrosion Rate (mil/yr)*					
	Sand Only		Sand + 10% VCI-A		Sand + 10% VCI-B	
	6-month coupons	12-month coupons	6-month coupons	12-month coupons	6-month coupons	12-month coupons
Overall Surface Average	1.65 1.90 2.16 **Average** **± std***	0.95 1.14 1.09 **1.48** **± 0.49**	0.92 0.57 1.27 **Average** **± std***	0.86 0.62 0.59 **0.81** **± 0.27**	0.75 1.16 0.76 **Average** **± std***	0.75 0.77 0.88 **0.85** **± 0.16**
Pitting (maximum)	12.5 9.7 24.6 **Average** **± std***	7.0 13.3 11.4 **13.08** **± 6.07**	26.2 15.4 22.0 **Average** **± std***	13.0 13.0 8.1 **16.28** **± 6.64**	14.3 23.7 14.3 **Average** **± std***	10.5 15.0 10.8 **14.77** **± 4.78**

*1 mil/yr = 25 μm/yr
**Average values are calculated for 6 coupons for each electrolyte and corrosion type combination
*** std denotes standard deviation of the data used to estimate average value

Table 3. Corrosion rates for sand-contact coupons in sand and sand + 1% VCI

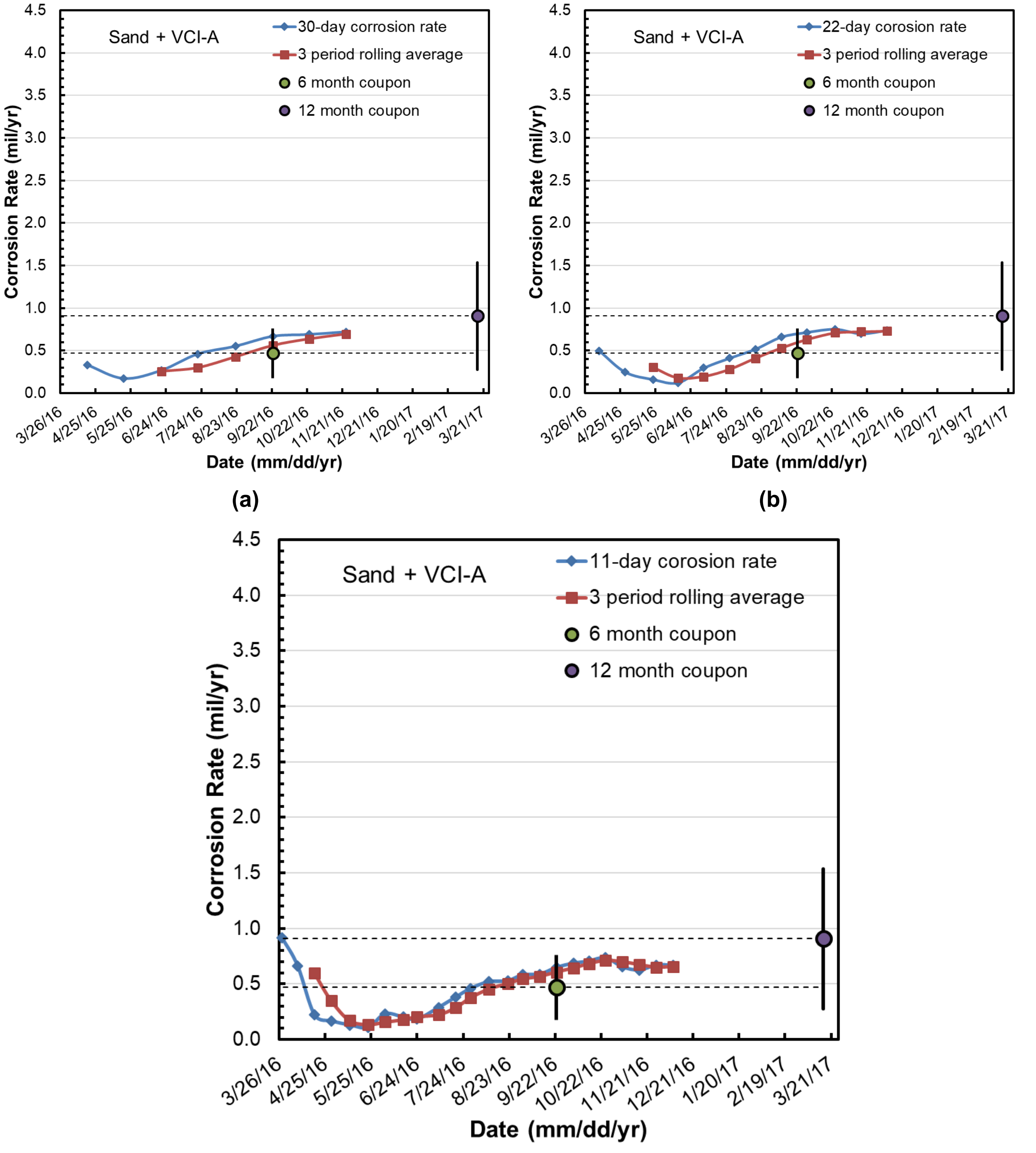
Corrosion Type	Corrosion Rate (mil/yr)*					
	Sand Only		Sand + 1% VCI-A		Sand + 1% VCI-B	
	6-month coupons	12-month coupons	6-month coupons	12-month coupons	6-month coupons	12-month coupons
Overall Surface Average	1.65 1.90 2.16 **Average** **± std***	0.95 1.14 1.09 **1.48** **± 0.49**	1.53 1.37 1.10 **Average** **± std***	0.74 0.77 0.92 **1.07** **± 0.32**	1.20 1.12 1.03 **Average** **± std***	0.69 0.79 0.84 **0.95** **± 0.20**
Pitting (maximum)	12.5 9.7 24.6 **Average** **± std***	7.0 13.3 11.4 **13.08** **± 6.07**	17.8 11.8 15.8 **Average** **± std***	6.1 7.2 8.5 **11.20** **± 4.78**	10.5 10.6 9.6 **Average** **± std***	6.8 7.7 7.0 **8.70** **± 1.74**

*1 mil/yr = 25 μm/yr
**Average values are calculated for 6 coupons for each electrolyte and corrosion type combination
*** std denotes standard deviation of the data used to estimate average value



(c)

Figure 2. (a) Monthly, (b) 22-day, and (c) 11-day corrosion rates using ER probe data for sand-only electrolyte. Three period rolling averages, average of surface average corrosion rates for 6-month, and 12-month coupons are presented by green and purple symbols. Standard deviations of the 6- and 12-month coupons' corrosion rates are presented by black vertical lines at the coupons' corrosion rate data. The horizontal dash lines are to highlight range of coupon corrosion rates.



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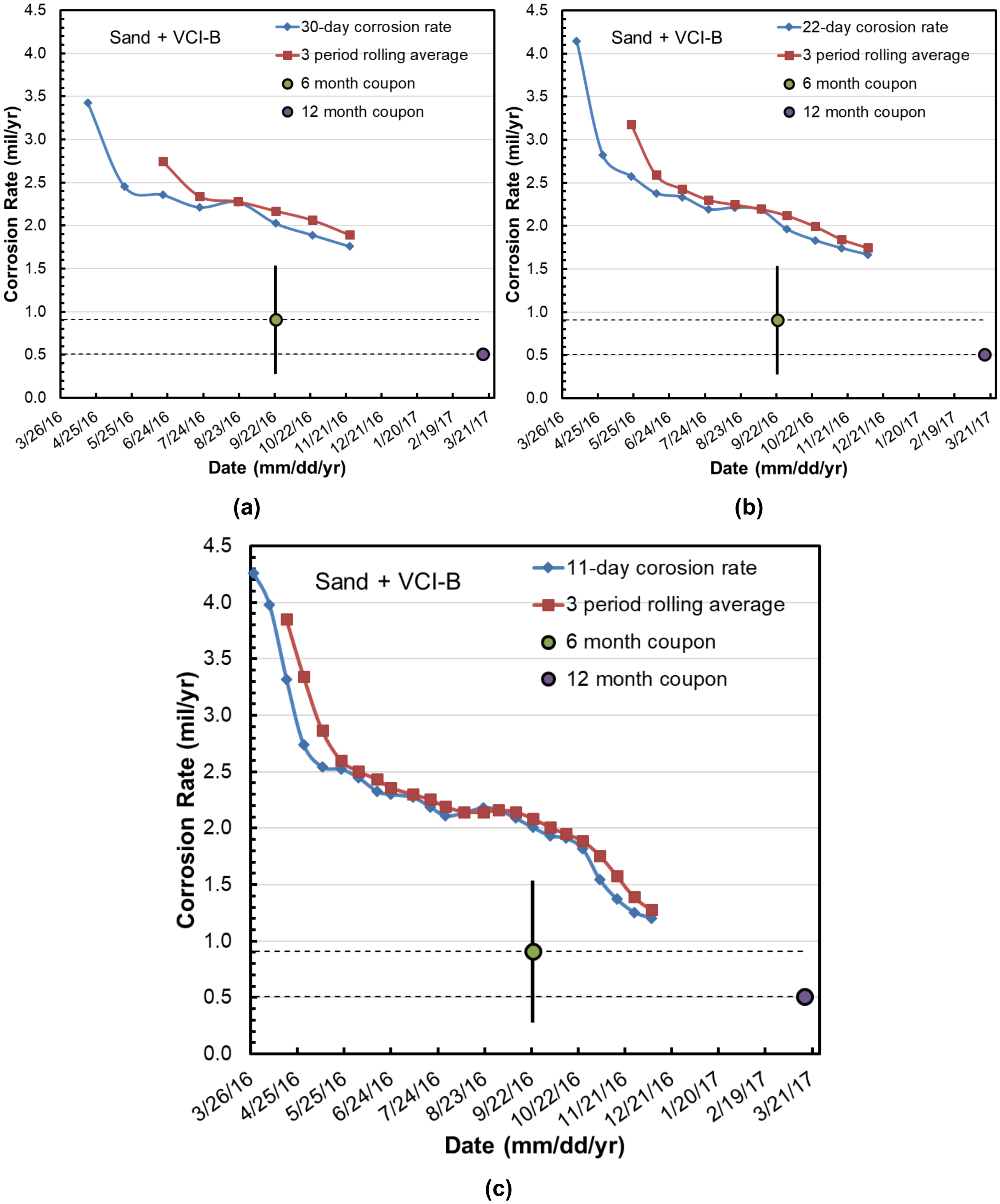

Figure 4. (a) Monthly, (b) 22-day, and (c) 11-day corrosion rates using ER probe data for sand plus 100% VCI-B electrolyte. Three period rolling averages, average of surface average corrosion rates for 6-month, and 12-month coupons are presented by green and purple symbols. Standard deviations of the 6- and 12-month coupons' corrosion rates are presented by black vertical lines at the coupons' corrosion rate data. The horizontal dash lines are to highlight range of coupon corrosion rates.

ER probe derived data provide measurement of the average corrosion rates, whereas pitting corrosion is the dominant contributor to overall corrosion and failure of the tank bottom plates. While there were agreements between ER-probe and coupons' surface average corrosion rates; ER probes and coupon agreement indicated that there exists a correlation that can be derived between the surface average and pitting corrosion rates. The correlation could be used to estimate pitting corrosion rates using the ER-probe derived corrosion rates.

Additional analysis was conducted to determine a correlation between the ER probe corrosion and coupons' pitting corrosion rates which are listed in Tables 1-3. Averages of coupons' surface average corrosion rates versus averages of pitting corrosion rates are plotted in Figure 5. As seen in the figure, there is a positive correlation between the surface average and pitting rates. Of the seven data points, five data points are close to the blue line in Figure 5, but the remaining two data points are above the straight line. The two data points farther away from the blue line are for sand + 10% VCI-A, and sand + 10% VCI-B. Proximity of the five data points around the blue line in Figure 5 indicate a positive correlation between the surface average and pitting corrosion rates.

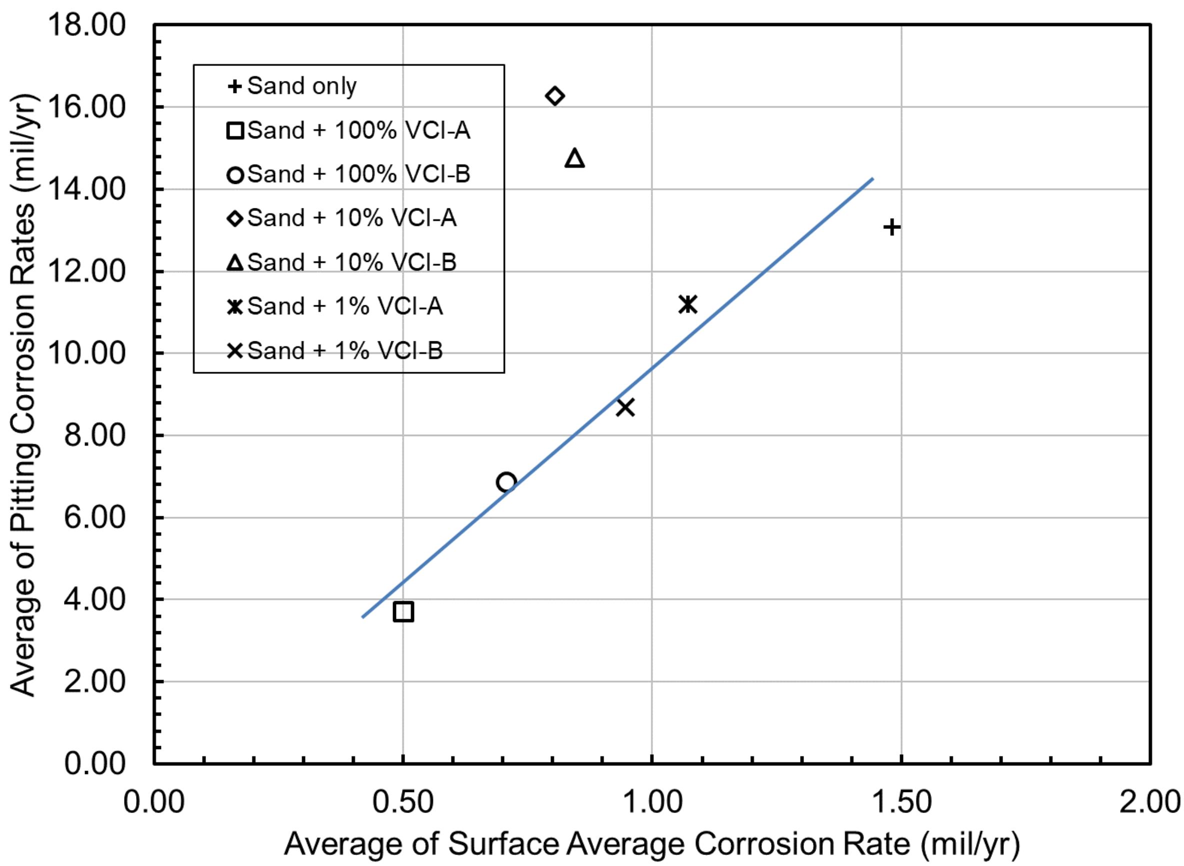

Figure 5. Averages of surface average corrosion rate versus average of pitting corrosion rate for coupons

The correlation between the surface average and pitting corrosion rates for sand, sand + 100% VCI-A, and sand +100% VCI-B is expressed by following equation:

$$\text{Pitting corrosion rate} \cong 10 \times \text{Surface average corrosion rate}$$

It is recognized that the above correlation is based on only five data points. Additional work is needed to further strengthen technical basis correlating pitting and surface average corrosion rates.

CONCLUSIONS

Electrical resistance (ER) probes are based on bulk resistance measurements, and thus, are designed to measure the average corrosion rate based on average metal loss; however, pitting is the dominant contributor to the overall corrosion and failure of the AST bottom plates. Analyses of ER probe and coupon corrosion rate data demonstrate that ER probes can accurately measure the surface average corrosion rates which are representative of the bottom plate corrosion rates, but a time-lag may exist between the two. It was also determined that ER probes were able to monitor the effect of the VCIs by monitoring corrosion rate in the sand electrolyte; ER probes were able to detect dosing of the sand bed with VCI by way of corrosion rate measurement. The data analyses also showed that there is a positive correlation between the surface average and pitting corrosion rates for sand, sand + 100% VCI-A, and sand + 100% VCI-B. The correlation also envelops sand + 1% VCI-A, and sand + 1% VCI-B. The correlation could be used to estimate the pitting corrosion rates using the ER-probe derived corrosion rates.

Overall, the ER probe is a practical tool to monitor effectiveness of the VCIs by monitoring corrosion rate in the sand electrolyte. However, position of the ER probe with respect to the VCI dosage point must be considered in field installations. If an ER probe is close to the VCI dosage location whereas the tank bottom is not able receive VCI, the ER probe data may not be representative of the tank floor corrosion rate at locations further from the dosage location.

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