

Atmospheric Corrosion Monitoring with Time-of-Wetness (TOW) Sensor and Thin Film Electric Resistance (TFER) Sensor

Sungwon Jung, Young-Geun Kim, Hong-Seok Song,
Seung-Min Lee, and Young-Tai Kho

*R&D Center of Korea Gas Corporation
638-1, Il-Dong, Ansan city, Kyunggi-do, 425-790 Korea*

In this study, TOW sensor was fabricated with the same P. J. Serada's in NRC and was evaluated according to pollutant amount and wet/dry cycle. Laboratorily fabricated thin film electric resistance (TFER) probes were applied in same environment for the measurement of corrosion rate for feasibility. TOW sensor could not differentiate the wet and dry time especially at polluted environment like 3.5% NaCl solution. This implies that wet/dry time monitoring by means of TOW sensor need careful application on various environment. TFER sensor could produce instant atmospheric corrosion rate regardless of environment condition. And corrosion rate obtained by TFER sensor could be differentiated according to wet/dry cycle, wet/dry cycle time variation and solution chemistry. Corrosion behaviors of TFER sensor showed that corrosion could proceed even after wet cycle because of remained electrolyte at the surface.

Keywords : atmospheric corrosion, time-of-wetness, electric resistance probe, corrosion rate

1. Introduction

Atmospheric corrosion develops when various metals are exposed under the environment that water such as rain and fog and pollutants such as SO_x, NO_x, and salt are present. Main parameters affecting atmospheric corrosion have been classified into humidity, pollutant, and temperature.

Among the parameters, pollutants facilitate water film to be formed and accelerate corrosion,¹⁾ corrosion reaction rate is increased with temperature, and the condition of high humidity and low temperature provides surface with water so that electrolyte as thin film can be formed at the surface.

It has been generally accepted that humidity condensate at the metal surface when relative humidity is higher than 80% and temperature is above 0 °C.^{2),3)} In such point, records on weather has been collected and used in the corrosion study.

Even temperature and relative humidity condition is met, however, which cannot be regarded as that electrolyte is present at the surface since electrolyte cannot be formed when temperature is sufficiently high.

Consequently, the need for direct measuring method of electrolyte presence led to the development of Time-of-

Wetness (TOW) sensor, its concept was based on the measurement of galvanic current between separated metal couples.^{4),5)}

In this study, TOW sensor was fabricated according to P. J. Serada's in NRC and was evaluated with pollutant amount and wet/dry cycle. Laboratorily fabricated thin film electric resistance (TFER) probes were applied in the same environment for the measurement of corrosion rate.

2. Experimental

The schematic diagram of TOW sensor is shown in Fig. 1.⁶⁾ Size is 25.5 mm × 12.5 mm, gap between two metals was 200 μm. Cu and Zn are coupled with Au respectively. Substrate material was polyimide, which could be applied to surface with curvature.

Target material was carbon steel (SM45C) and substrate was Al₂O₃, which is chemically stable and can enhance adhesion strength because of surface roughness. Deposition condition is summarized in table 1. Deposited thin film was patterned by silk screen and etched in ferric chloride resulting to multi-lined thin film (Fig. 2).

Test chamber for exposure of TOW and TFER sensor was 50 cm x 30 cm x 30 cm, environment was controlled by both the ultrasonic humidifier and drier. The schematic

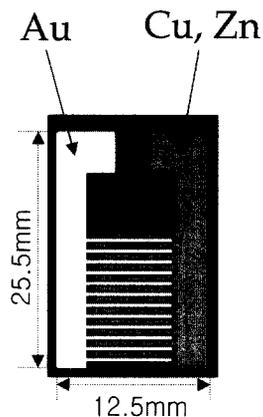


Fig. 1. Schematic diagram of TOW sensor.

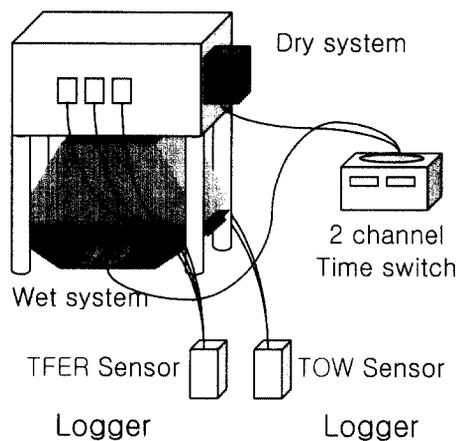


Fig. 3. The schematic diagram of test chamber.

Table 1. Deposition condition of TFER sensor.

Target	SM45C
base pressure	1.9×10^6 torr
working pressure	2mtorr
Power	200W
	$310V \times 0.645A$
gas ratio	Ar : 10sccm
sub-temp	room-temp.

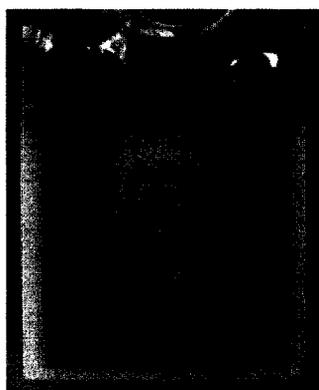


Fig. 2. Photograph of fabricated TFER sensor.

diagram of test set-up is shown in Fig. 3.

Test solutions were distilled water and simulated sea water 3.5% NaCl. Time interval in wet/dry cycle was varied for test, which time interval was 20 min./40 min., 20 min./60 min., 120 min./240 min., 480 min./960 min.. It was observed that relative humidity in dry cycle was below 60% and that in wet cycle was 100%. Galvanic potential in TOW sensor and change of resistance in TFER sensor were logged continuously.

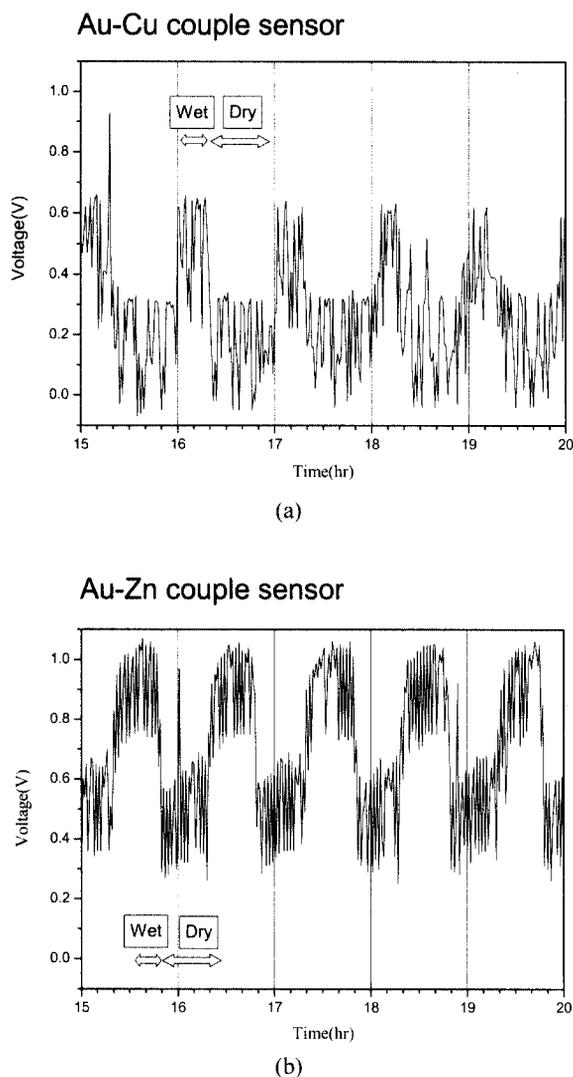


Fig. 4. Results of TOW sensor under distilled water condition. (wet/dry time : 20 min/40min)

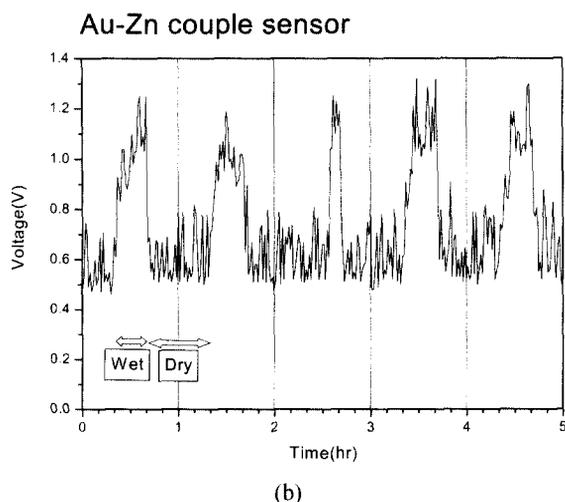
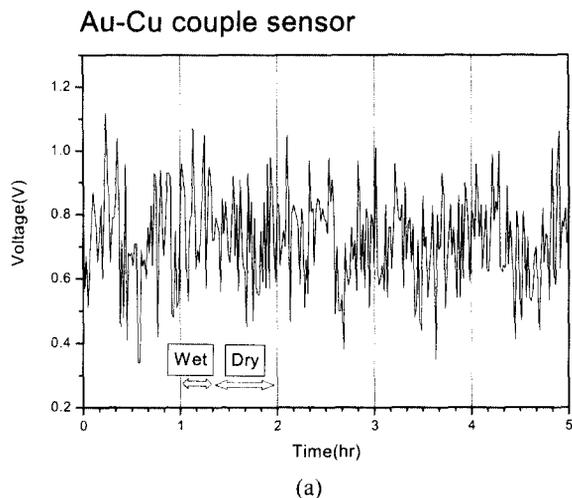


Fig. 5. Results of TOW sensor under NaCl 3wt % solution condition.(wet/dry time : 20 min/40min)

3. Results and discussion

The results of two TOW sensors in distilled water environment are shown in Fig. 4. Fig. 4 (a) shows that potential difference 0.6V was measured during wet cycle and 0V to 3V was measured during dry cycle. Overall behaviors showed discrete wet/dry cycle. Potential difference measured in Au-Zn couple sensor (Fig. 4 (b)) was larger than Au-Cu sensor resulting from emf potential difference.

However, we/dry cycle could not be discerned under the condition of Au-Cu couple sensor in 3.5% NaCl (Fig. 5 (a)). This could be attributed to the hydrophilic property of salt remained after wet cycle. And wet/dry cycle could not be also clearly discerned even in Au-Zn couple (Fig. 5 (b)). These results suggest that TOW sensor might not

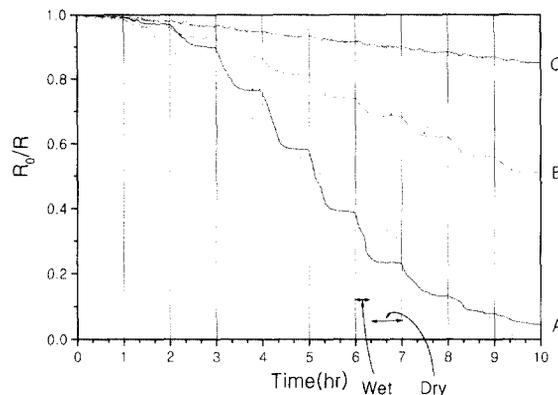


Fig. 6. Behaviors of TFER sensor under distilled water condition. (wet/dry time : 20 min/40min)
Line width : A(0.079 mm), B(0.158 mm), C(1.58 mm)

Table 2. Results of corrosion rate obtained by TFER sensor at distillation water

Sensor	Line width(mm)	gradient	Corrosion rate (mpy)
A	0.079	0.00199	0.412 mpy
B	0.158	7.57809×10^{-4}	0.157 mpy
C	1.580	2.72687×10^{-4}	0.056 mpy

be reliable tool to monitor wetted time for classification of corrosivity especially in polluted environment.

Atmospheric corrosion proceeds initially in the type of pit, therefore it can be expected that corrosion rate could be measured directly by applying thin lined ER sensor. With this point TFER sensors with different line width were evaluated in the same condition like TOW sensor test.

In Fig. 6, results of TFER sensor applied into wet/dry in distilled water are shown. In which TFER sensor with small width line (0.079 mm) shows highest gradient among various sensors. Calculated corrosion rate is summarized in Table 2. The reason why TFER with narrow line width has higher corrosion rate can be attributed to prompt decrease in resistance since developed pit lead to the loss of most line.

Corrosion rates during 1 cycle are shown in Fig. 7, in which corrosion rate at dry cycle is negligible and higher corrosion rate can be calculated compared with corrosion rate obtained from overall wet/dry cycles.

Behaviors of TFER sensor at NaCl 3.5% solution is shown in Fig. 8 and calculated corrosion rates are summarized in Table 3. TFER sensor with smallest line width has highest corrosion rate than others, and both TFER sensors with 0.158, 1.58 mm respectively show similar corrosion behavior. This is because corrosion proceeds

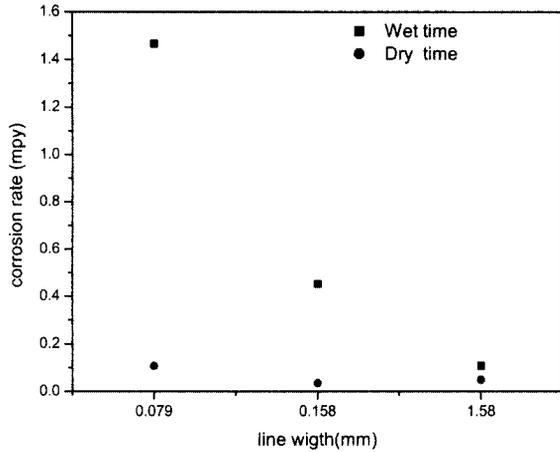


Fig. 7. Corrosion rates of TFER sensor at 1 cycle.

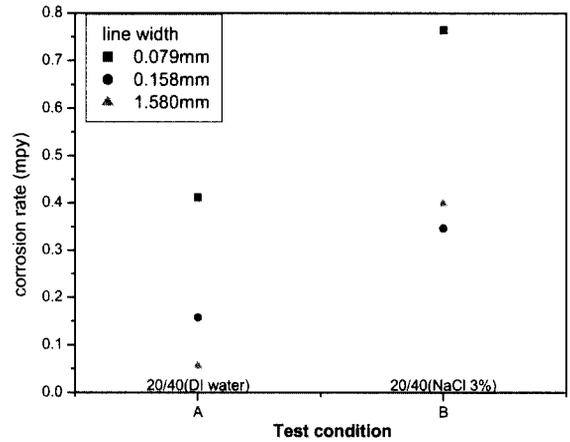


Fig. 9. Corrosion rate of TFER sensor at solution condition.(solution : distilled water, NaCl 3.5 wt% solution)

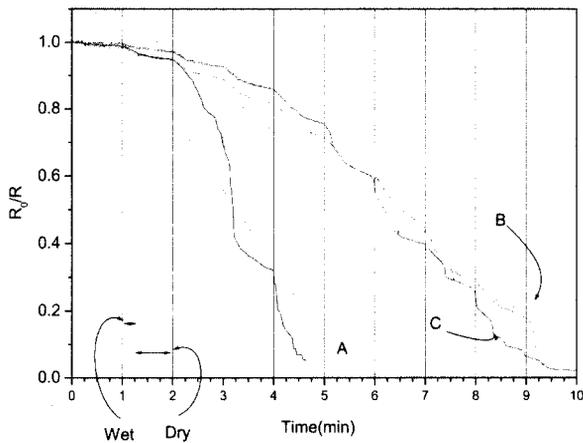


Fig. 8. Behaviors of TFER sensor under NaCl 3.5 wt% solution condition.(wet/dry time : 20 min/40min)
Line width : A(0.079 mm), B(0.158 mm), C(1.58 mm)

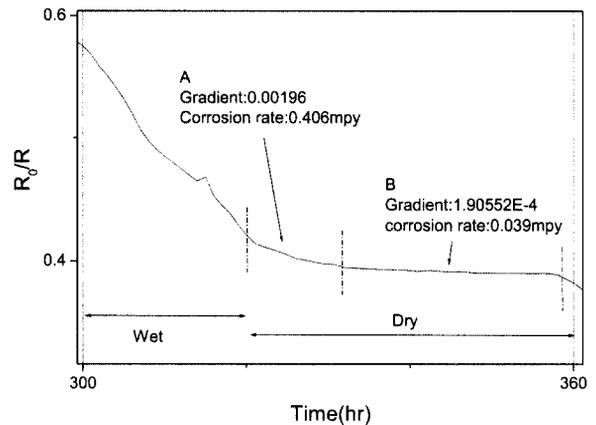


Fig. 10. Change of corrosion rate during 1 cycle in Fig. 8.

Table 3. Results of corrosion rate obtained by TFER sensor at NaCl 3.5 wt% solution

sensor	Line width (mm)	Gradient	Corrosion rate (mpy)
A	0.079	0.0037	0.765 mpy
B	0.158	0.00193	0.346 mpy
C	1.580	0.00167	0.399 mpy

quickly owing to Cl⁻ aggressiveness.

As shown in Fig. 9, corrosion rates measured in 3.5% NaCl solution are higher than distillation water because corrosion reaction in distilled water is controlled only by limited anodic reaction while corrosion reaction in 3.5% NaCl solution is controlled only by oxygen cathodic reaction.

It was observed in TFER behaviors that corrosion could

proceed to the degree of 0.4mpy during initial dry cycle right after wet cycle finishing in NaCl solution (Fig. 10). This is because not fully evaporated water film contribute to corrode, which suggest important point that only wet time monitoring could not be related with corrosivity and consequent consideration for classification of corrosion rate.

In Fig. 11. corrosion rates with different wet/dry cycle time is shown, in which corrosion rate with short wet/dry cycle shows higher than those with long cycle even although total wet and dry time is same regardless of cycle time. Corrosion rates of TFER sensor with 120 min./240 min. wet/dry cycle in distilled water as shown in Fig. 12 shows negligible difference between TFER sensors with various lines. However, corrosion rates of TFER sensor was could be obtained discretely with line width.

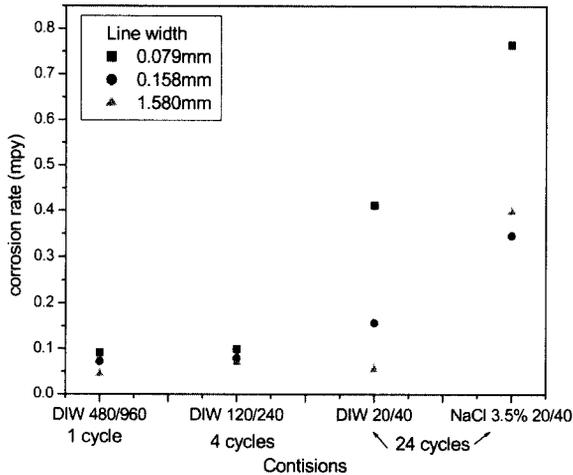


Fig. 11. Corrosion rate at various cycles.

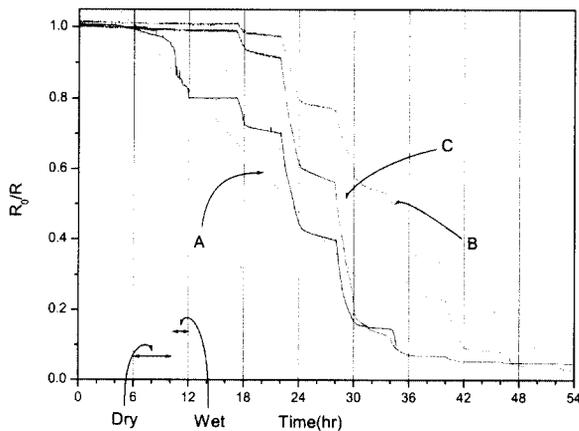


Fig. 12. Behaviors of TFER sensor under distilled water condition.(wet/dry time : 120 min/240 min)
Line width : A(0.079 mm), B(0.158 mm), C(1.58 mm)

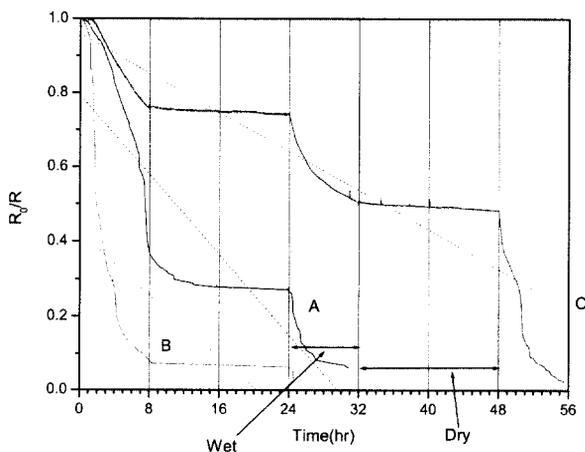


Fig. 13. Behaviors of TFER sensor under distilled water condition.
(wet/dry time : 480 min/960min)
Line width : A(0.079 mm), B(0.158 mm), C(1.58 mm)

4. Conclusions

1) TOW sensor could not differentiate the wet and dry time especially at polluted environment like 3.5% NaCl solution. This implies that wet/dry time monitoring by means of TOW sensor need careful application on various environment.

2) TFER sensor could produce instant atmospheric corrosion rate regardless of environment. And corrosion rate obtained by TFER sensor could be differentiated according to wet/dry cycle, wet/dry cycle time variation and solution chemistry.

3) Corrosion behaviors of TFER sensor showed that corrosion could proceed even after wet cycle because of remained electrolyte at the surface.

Acknowledgments

Support was provided by the National Research Laboratory Program of Ministry of Science and Technology.

References

1. P. W. Brown and L. W. Masters, Atmospheric Corrosion, W. J. Ailor, ed., Wiley, New York, p.31 (1982).
2. Sheldon W. Dean and David B. Reiser, Time of Wetness and Dew Formation: A Model of Atmospheric Heat Transfer, STP1239, p.3
3. ASTM G1.04
4. International Standard, ISO 9223:1992 (1992).
5. P. J. Serada, ASTM STP 767, p.267, STP 558, p.7
6. Standard Practice for Measurement of Time-of-Wetness on Surfaces Exposed to Wetting Conditions as in Atmospheric Corrosion Testing, ASTM G84-89 (1999).