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Online Atmospheric Corrosion Monitoring for Kuwait Field Research Stations for Building Construction Materials

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Abstract

Currently two field research station has been established in Kuwait for monitoring building materials performance for concrete in Kuwait environments. The two field site selection has been based upon an outcome of a research investigation for monitoring the atmospheric corrosivity from eight areas in different locations in Kuwait.

Data on corrosivity of the atmosphere are essential for the development and specification of an optimized corrosion resistance system for reinforced concrete manufactured products. The corrosivity category is a technical characteristic which provides a basis for the selection of materials and protective measures in atmospheric environments subject to the demands of the specific application particularly with regard to service life. In the concerned work, the corrosivity categories of different locations in Kuwait are being classified according to standard ISO 9223 based on the time of wetness and bimetallic corrosion rate data obtained from eight corrosion monitoring stations. Results have been able to distinguish heavily polluted areas like Al-Zoor and Fahaheel, highly vulnerable to corrosion from those like Sabia and Rabiya with low corrosion rates due to comparatively low level of atmospheric pollutants. Atmospheric Corrosivity station with data monitor and design supported with GSM remote data acquisition system was installed at the eight outdoor strategic locations in Kuwait. The sites of exposure were chosen according to weathering classification as marine, desert, and industrial marine environments where the metals and rebar's concrete are likely to be used.

In its present form, the electrochemical sensors were found to be suited to atmospheric Time of Wetness (TOW) and corrosion rate estimation in Kuwait, and the measurement technique provided a good indication of variations in the conductivity of the thin electrolyte film present on the probe face. It has also provided useful information relating corrosion of outdoor atmospheric exposure panels to the weathering corrosion activity on the probe elements.

Keywords: Field research station, Atmospheric corrosivity sensors, Kuwaiti environment, Corrosion in rebar concrete, Atmospheric Pollution, Corrosion Monitoring, Time of Wetness (TOW).

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1. INTRODUCTION

Atmospheric corrosion accounts for the highest overall cost and metal loss of all the fundamental corrosive environments. It is defined as a thin aqueous layer between the surface of the corroding material and the atmosphere. Three phases, solid (corroding substrate), liquid (thin aqueous layer) and gaseous (atmosphere) and the interfaces between these phases are therefore important and can be used in corrosion monitoring principles. Corrosion monitoring in outdoor and indoor atmosphere poses specific challenges related to characterizing corrosion damage generally taking place at a low rate in a short practical time frame.

Metals, alloys and metallic coatings may suffer atmospheric corrosion when their surfaces are wetted. The nature and rate of attack depends upon the properties of surface formed electrolytes, particularly with regard to the level and type of gaseous and particulate pollutants in the atmosphere and the duration of their action on the metallic surface. Categorization of corrosivity of atmosphere provides a basis for the selection of materials and protective measures in atmospheric environments subject to the demands of the specific application particularly with regard to service life. Unfortunately, the area of atmospheric corrosion monitoring for the State of Kuwait, especially in predictive capability, has not benefited much from recent advances in atmospheric corrosion field. The main difficulty has been thought to be the desert climatic condition of Kuwait and that the amount of electrolyte condensed on a metal surface is too limited for reliable measurement of electrochemical parameters. The recent advancement of cost effective micro-sensors based on modern vacuum deposition technology makes the fabrication of micro-sensors practical and form the base for recent corrosion sensor development. This technology is found to be useful for studying atmospheric corrosion under Kuwait environment, where reactions take place in ultra-thin, localized condensed water layer on metal surfaces

Electrochemical probes of various types have been used in atmospheric corrosion studies for approximately twenty years. However, until recently, the majority of studies had employed pairs of dissimilar metals, galvanically coupled. Such measurements attempts to estimate the “Time of Wetness” (TOW) parameter, i.e. the time period during which the test probe is wetted either by condensation or by rainfall. It is usually assumed that significant corrosion damage occurs only during these periods. The measurement of the galvanic corrosion current can be carried out using a sensitive current to voltage converter (zero resistance ammeter or ZRA) with operational amplifier (OPM). It is usual to record the total period during which the output of this device exceeds a preset limit, this being time of wetness parameter.

Commercial probes are now available which utilize interlaced gold plated fingers on fiber-glass substrate. This simple approach does not give the actual corrosion rate, although a reasonable estimate can usually be made of the total metal loss over a period of time.

Alternatively, it is possible to record the magnitude of the coupling current. Integration over the time of test then gives the total charge passed. This can be converted to the metal loss due to corrosion, using a suitable empirically obtained scaling factor. This factor is dependent on both cell geometry, the electrode material and on the exposure conditions. An estimate of the corrosion rate can then be made ; since it is possible to theoretically predict that the corrosion current density will be proportional to the inverse of the cell resistance, measured by the corrosion rate sensor. The linear polarization measurement technique comprised of two identical electrode and relies on the application of a small (<20 mV) potential across the sensor test cell, measuring resultant current, or vice versa.

The main objective of this study was to demonstrate that the Corrosivity of Kuwait marine industrial atmosphere is measurable using sensitive electrochemical techniques and that these can be used in conjunction with continuous monitoring of physical and chemical parameters and computer analysis of the data to pinpoint the time periods and parameter combinations which give rise to increased corrosion rates

The knowledge of the effects of the various naturally occurring combinations of pollutants and meteorological parameters could then be used in conjunction with continuous electrochemical monitoring to predict on a continuous basis the Corrosivity of the site atmosphere with respect not only to mild steel but also to other structural building materials and electronic devices.

Kuwait atmospheric corrosivity station

The Kuwait Atmospheric Corrosivity Monitor has been designed by the CISRO Manufacturing and infrastructure Technology Australia (6). This unit records the environmental parameters that are important for corrosion. Used in combination with pollutant monitoring equipment such as ISO Salt Candle, estimates of the Corrosivity of the environment can be made.

The system shown in Fig. 1 includes a bimetallic corrosion sensor. This enables the unit not only to provide ISO time of wetness (TOW) and Grid (TOW), but also the corrosion rate of the bimetallic sensor. The wetness grid and surface temperature sensors are seen here attached to a stainless steel plate.

The incorporated GSM modem with power supply (10-18 V DC) allows:

- Remote downloading of data with data logger engine specified as Data Taker DT50
- SMS messaging (including interrogation)
- Alleviates need for fixed telephone line

Specifications of Probe Sensors Relative humidity and Temperature sensors type: Vaisala Humitter,

Temperature accuracy better than ±0.6°C and RH accuracy better than ±5%

1. Wetness grid: Gold finger-jointed grid mounted on sintered alumina
2. Bimetallic corrosion sensor: Gold/Zinc, or Copper/Aluminum
3. Surface temperature sensor: PT100

Salt Candles The wet Salt Candles allows accurate measurement of fluoride, chloride, nitrite, bromide, phosphate and sulfate cations; and lithium, sodium, ammonium, potassium, magnesium and calcium anions. The candles as described in ISO 9225 are used to trap and collect air-borne pollutants to determine the corrosive effect of the atmosphere in an area. They consist of a bottle containing a 40% glycerol solution and gauze wick that protrudes above the bottle. An aliquot of this solution is then analyzed for chloride ions according to ISO 9225. Alternatively an aliquot of the solution can be analyzed for the rate of deposition of many ions using Ion Chromatography. The deposition rate is expressed in (mg/m^2 day).

2. MATERIALS AND METHODS

Atmospheric Corrosivity monitoring stations and Salt Candles were conducted at 8 test sites in Kuwait. The locations of these sites were in Kuwait populated areas along the Gulf of Kuwait coast next to major sources of pollution, (Figure 2). These sites vary considerably with respect to moisture content, temperature and contaminants (e.g. dust content and gaseous impurities). These sites, therefore, have been divided according to classification of weathering types. Failakah Island, KISR Main Building and Sabia City Area were classified as marine which is expected to be affected by particles of sea salt (e.g. chlorides) carried by wind and deposited on materials. Dasman Area was classified as urban site. It is subjected to normal precipitation patterns and typical urban contaminants emitted by traffic. Fahaheel and Al-Zoor Texaco Areas were classified as marine industrial area. These sites are identified with heavy industrial manufacturing and oil refineries facilities.

The atmosphere in both areas can contain concentrations of SO_2, chlorides, nitrates or other specific industrial emissions that are released from sources located nearby. Al-Rabia area is a light weight industrial area and Al-Jahra Hospital area, they are located close to the sewage treatment plant and hence classified as urban and light industrial polluted area. Outdoor atmospheric racks were also placed next to the Atmospheric Corrosivity monitor.

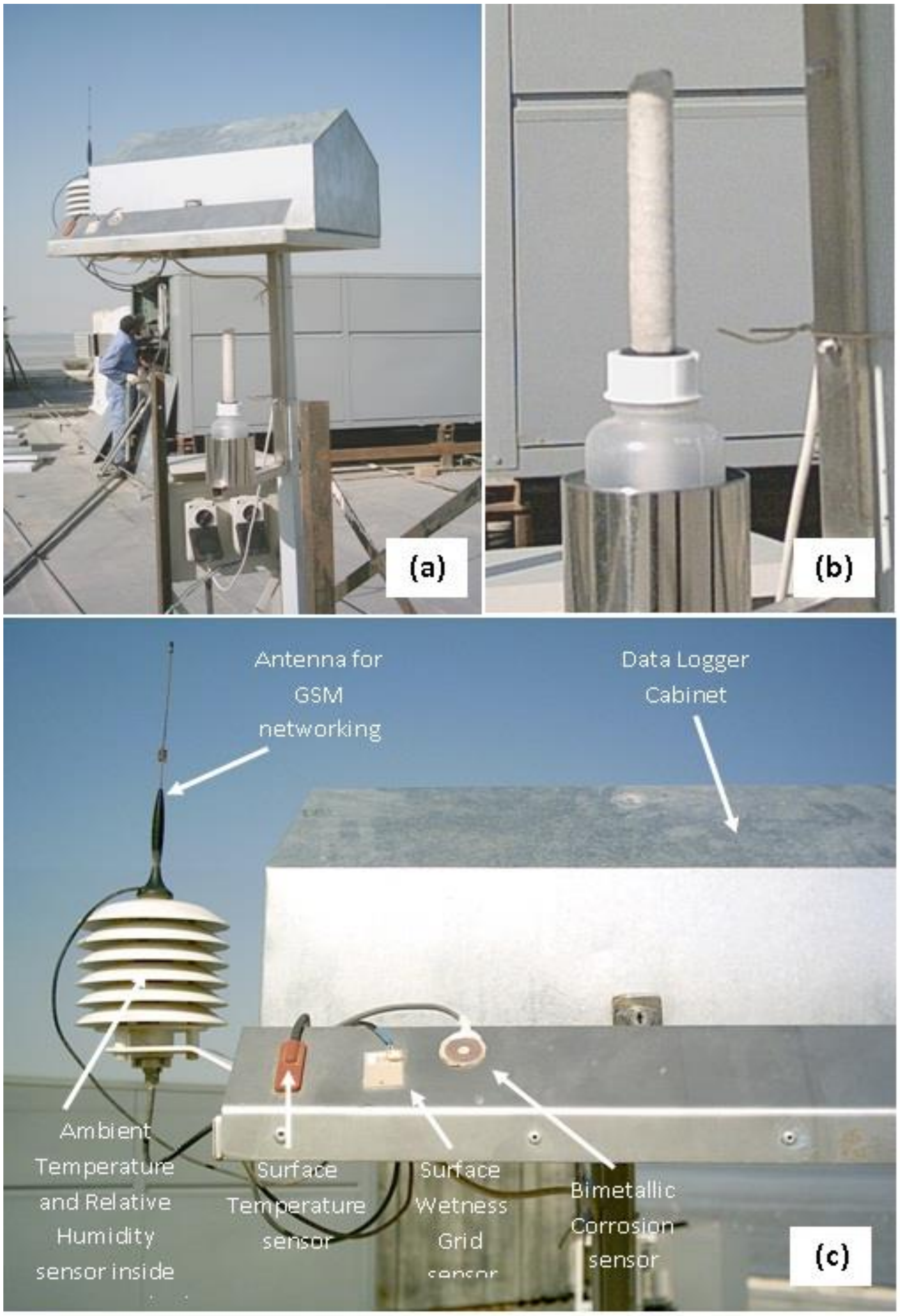


Figure1 Atmospheric Corrosivity Monitoring Station in Kuwait. (a) Overall view on site. (b) Salt Candle and (c) Close-up to reveal sensors.

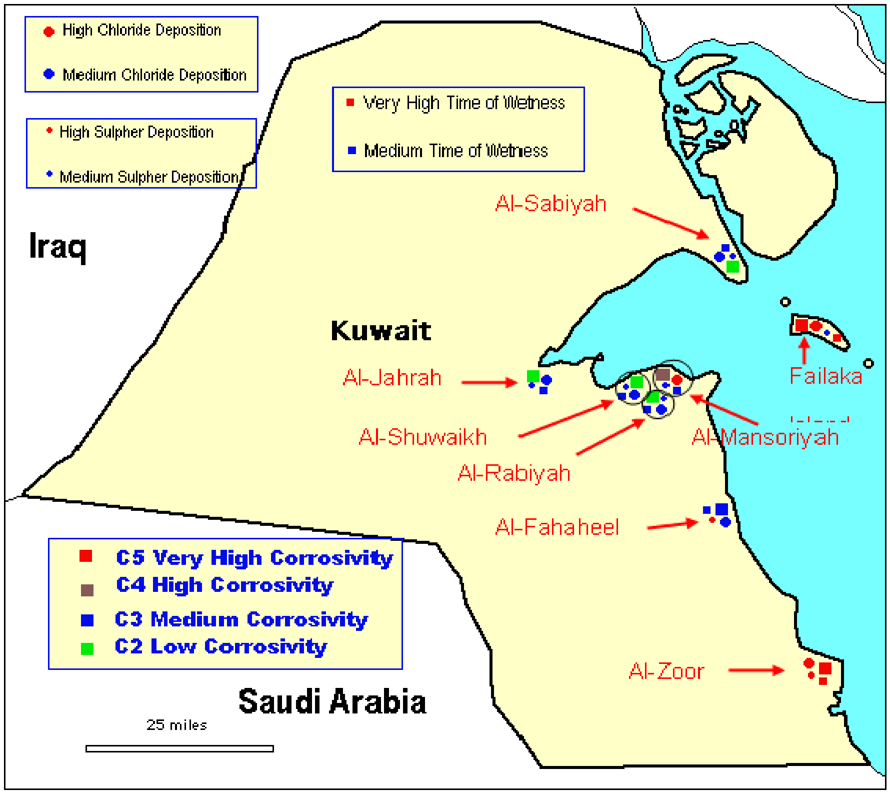


Figure2 Atmospheric Corrosivity map of Kuwait

3. Results and Discussion

It has been decided for the purpose of this paper to limit the presentation of the Atmospheric Corrosivity monitor data to Sabia Station and Al Zoor Station only to one cumulative daily data plot instead of a series of progressively more detailed plots of all areas in Kuwait. Figures 3 and 4 present the daily averages for of bimetallic corrosion, time of wetness (TOW), relative humidity RH with air and surface temperature. The plot represent the exposure period from 4 Aug 2004 to 23 Feb 2005 (i.e. 7 months). The months of exposure were split into two variables with the first three months as one variable and the last four as another. This is because initial examination of the plots of the data indicated a distinct difference in rates of change for the two periods of time (see Figure 3 and 4). The atmospheric corrosion rate has shown that the electrochemical data reflect the same trends as the TOW, RH and surface temperature and gave useful information concerning seasonal changes of corrosion rates. The trends of seasonal data indicated that as the temperature increases RH decreases and the layer formed by dew become thinner and thinner until all surface electrolytes has disappeared.

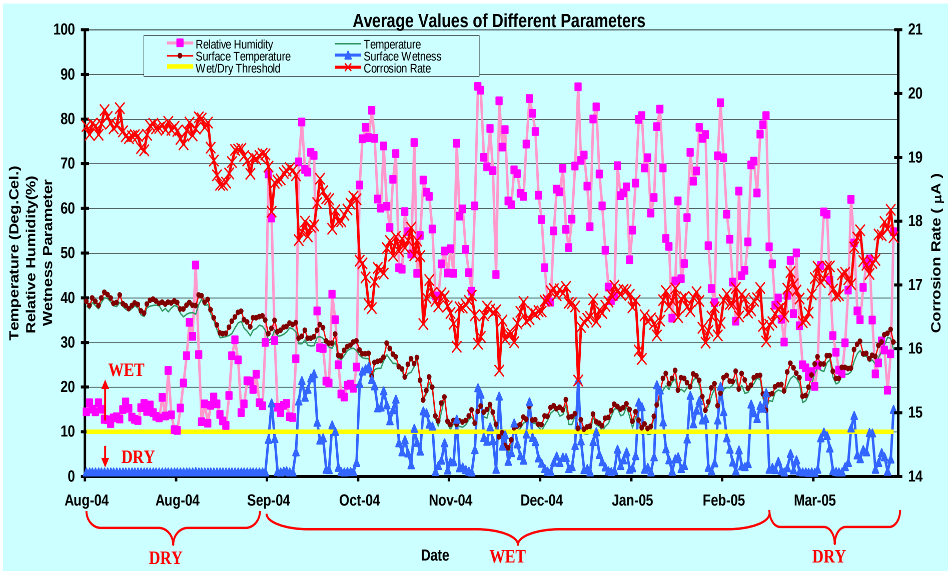


Figure 3. Atmospheric Corrossivity data for Sabia Station North of Kuwait, showing, bimetallic corrosion, TOW, R.H, surface temperature and air temperature

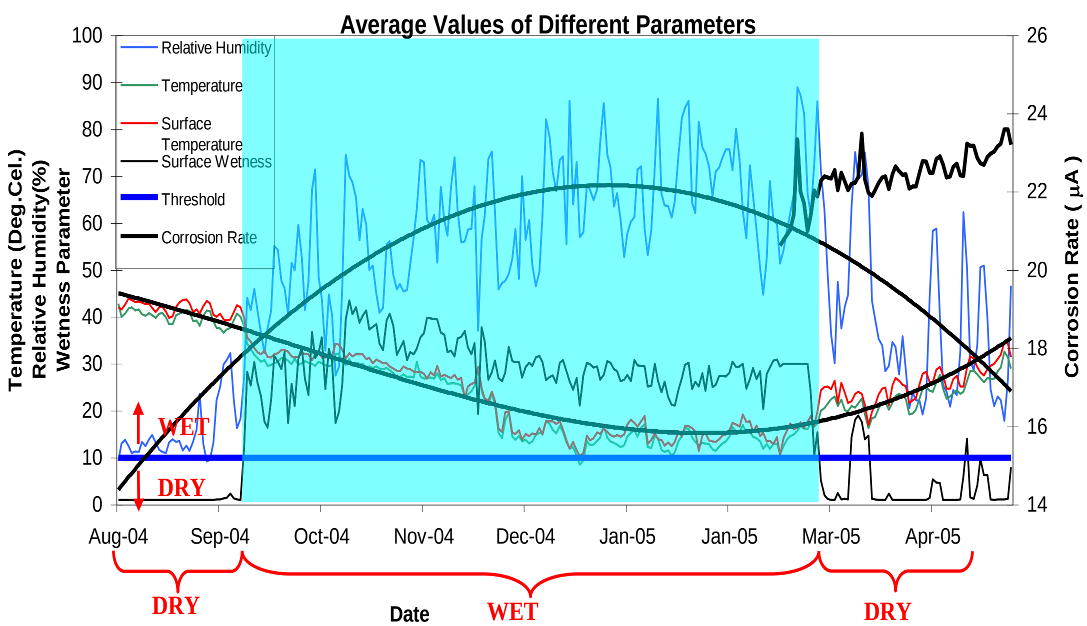


Figure 4. Atmospheric Corrosivity data obtained for Al-Zoor Texaco Station Site South of Kuwait, showing, bimetallic corrosion, TOW, R.H, surface temperature and air temperature.

The following Figs. 5 to 7 lists atmospheric corrosivity data obtained to characterize the daily, weekly, and hourly performance of the corrosivity monitor located at Sabia and Al Zoor stations.

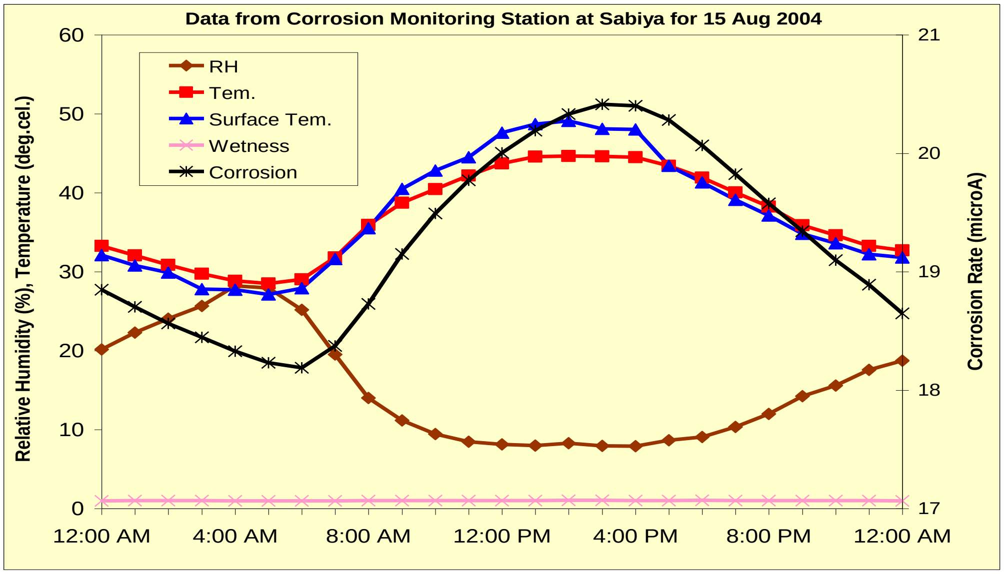


Figure 5. Atmospheric data for Sabia on 15 August showing one day profile of RH, Temperature, Surface Temp, wetness, and corrosion rate

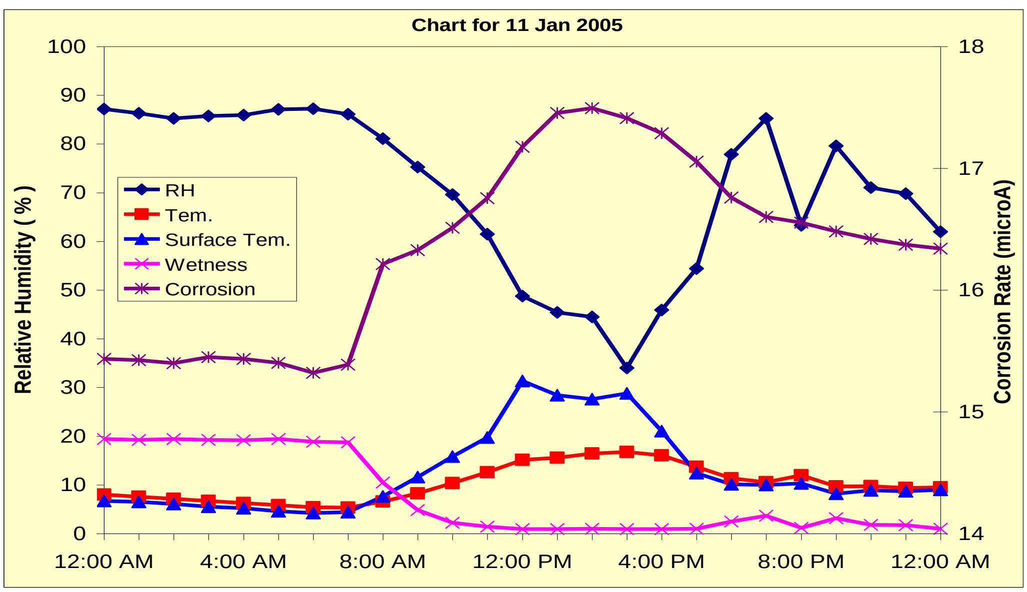
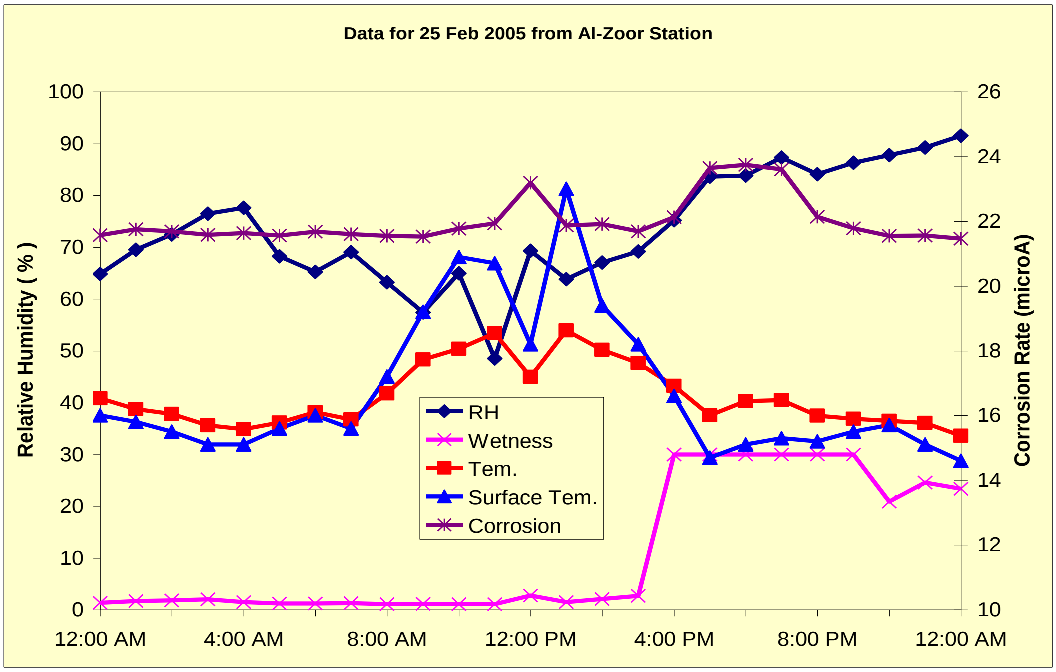


Figure 6. Atmospheric data for Sabia on 10 & 11 January 2005, showing two days hourly profiles of RH, Temperature, Surface Temp, wetness, and corrosion rate



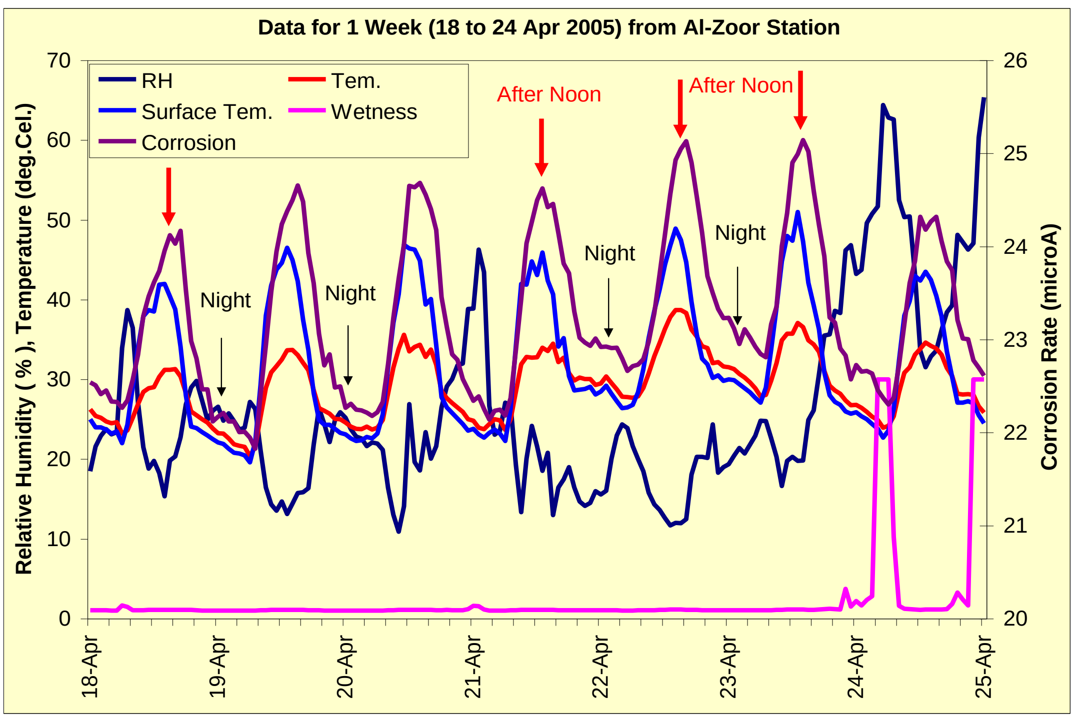


Fig. 7. Atmospheric data for Al Zoor area on 25 February &18 to 24 April 2005, showing (a) one days and (b) two weeks hourly profiles of RH, Temperature, Surface Temp, wetness, and corrosion rates

Tables 1 to 4 present the classification of different locations in Kuwait based on time of wetness, deposition rate of SO2, deposition rate of Chlorides and overall categorization of corrosivity, respectively. Table 5 summarizes these findings along with the average corrosion rate obtained from bimetallic sensors.

Table1 Classification of time of wetness

Time of wetness		Category	Locations in Kuwait
Hours per year (h/a)	%		
$T \leq 10$	$T \leq 0.1$	T_1	
$10 < T \leq 250$	$0.1 < T \leq 3$	T_2	
$250 < T \leq 2500$	$3 < T \leq 30$	T_3	Fahaheel, Sabiyah, Rabiyah, Mansoriya, Shuwaikh(KISR), Jahra
$2500 < T \leq 5500$	$30 < T \leq 60$	T_4	
$5500 < T$	$60 < T$	T_5	Failaka, Al-Zoor

Table 2 Classification of pollution by sulphur-containing substances represented by SO_2

Deposition rate of SO_2 mg/(m^2.d)	Concentration of SO_2 μg/m^3	Category	Locations in Kuwait
$P_d \leq 10$	$P_c \leq 12$	P_0	
$10 < P_d \leq 35$	$12 < P_c \leq 40$	P_1	Al-Rabiyah, Al-Sabiyah, Al-Jahra, Mansoriya, Shuwaikh, Failaka
$35 < P_d \leq 80$	$40 < P_c \leq 90$	P_2	Al-Zoor, Fahaheel
$80 < P_d \leq 200$	$90 < P_c \leq 250$	P_3	

Table 3 Classification of pollution by airborne salinity represented by chloride

Deposition rate of chloride Mg/(m^2.d)	Category	Locations in Kuwait
$S \leq 3$	S_0	
$3 < S \leq 60$	S_1	Al-Rabiyah, Fahaheel, Al-Sabiyah, Al-Jahra, Shuwaikh
$60 < S \leq 300$	S_2	Mansoriya, Failaka, Al-Zoor
$300 < S \leq 1500$	S_3	

Table 4 Categories of corrosivity of the atmosphere

Category	Corrosivity	Locations in Kuwait
C_1	Very low	
C_2	Low	Al-Sabiyah, Al-Jahra, Shuwaikh, Al-Rabiyah,
C_3	Medium	Fahaheel
C_4	High	Mansoriya
C_5	Very high	Failaka, Al-Zoor

Table 5 Deposition rate of chloride and SO_2 along with the time of wetness and average corrosion rate for different sites in Kuwait.

Site	Deposition Rate of Chloride (mg/m2.day)	Deposition Rate of SO2 (mg/m^2.day)	Time of Wetness (%)	Corrosivity Category	Remarks (Corrosivity of Site)	Average corrosion rate (μA/cm^2)
Al-Zoor	150.00(S2)	35.02(P2)	62(T5)	C5	Very High	27.42
Failaka	79.80(S2)	25.95(P1)	87(T5)	C5	Very High	25.67
Mansoriya	68.92(S2)	21.90(P1)	13(T3)	C4	High	24.26
Fahaheel	13.94 (S1)	38.31(P2)	16(T3)	C3	Medium	22.57
Rabiyah	15.00(S1)	17.44(P1)	5(T3)	C2	Low-Medium	21.61
Jahra	23.35(S1)	18.55(P1)	9(T3)	C2	Low-Medium	20.78
Shuwaikh	35.19(S1)	24.47(P1)	5(T3)	C2	Low-Medium	20.10
Sabiyah	19.00(S1)	17.30(P1)	20(T3)	C2	Low-Medium	17.54

4. Conclusion

The following conclusions can be drawn from the data obtained form these corrosion monitoring stations.

1) The ambient air temperature and metal surface temperature vary in accordance with each other which are quite obvious. The average difference between the air temperature and metal surface temperature is 3 to 4°C. The interesting thing to note is that during the cold weather, metal surface temperature is usually less than the air temperature and in hot weather, metal surface experiences higher temperature than the ambient air temperature.

2) Relative humidity exhibits larger variations as compared to temperature variations over same period. The relative humidity trend is usually inversely proportional to the temperature trend. Generally high relative humidity has been observed in the period of cold weather and vice-a-versa. Over a period when temperature goes on increasing, humidity decreases and vice-a-versa.

3) Corrosion rate curve can be said to be directly proportional to the air temperature and surface temperature curves and inversely proportional to the relative humidity curve. Corrosion rates are low in winter (from Sep. to Feb.) and increases with increasing temperatures towards summer.

4) Surface wetness mainly depends on the relative humidity and temperature values. It has been observed in this data that the peaks in the relative humidity curve has affected TOW and caused the high peaks in wetness curve if the temperature is low. It can be roughly said that the high value of humidity (approximately above 50-60%) is responsible for the surface wetness only at lower temperatures (approximately below 35°C). At temperatures approximately above 40°C, the surface doesn't remain wet even at the higher humidity levels.

5) As can be seen in the chart for 1 week from Al-Zoor station data, during typical hot days, relative humidity level is generally low (less than 40 %) and the surface is not wet. But still we have higher corrosion rate curve which follow temperature curve. Therefore, peaks of temperature curves and corrosion rate curve are observed during afternoon hours and troughs are found at the mid night hours while relative humidity peaks are obtained at mid night time and troughs at afternoon. Even when high humidity and surface wetness is observed during a hot day, corrosion rate curve is found to follow temperature curve rather than the relative humidity curve or the surface wetness curve. This finding is contradicting to most of the observations found in literature (F. Mansfeld, 1982) where it is stated that most of corrosion activity on the metal surface occur when the surface is wet or when relative humidity is higher than 80 % at temperatures greater than 0°C (t_{80}^{o}). The reason for this contradiction may be the fact that most of these atmospheric corrosion studies were conducted in Europe and USA which are rather cold regions. One exception to this, which presents somewhat similar case to our observations in Kuwait, is from F. Mansfeld, 1994 who has reported

the observation of higher corrosion rates during summer and which is to be proposed to be caused by nitric acid produced by photochemical oxidation of NOx. This point needs further investigation.

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