Corrosion in control systems decrease the lifetime of the electronic devices of the industrial plants of Mexicali, BC, Mexico

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Paper received on 04/10/12, Accepted on 24/10/12.

Abstract. The principal factor to obtain the economical value of the products manufactured in the electronics industry is due to the production yielding. In this city are around an 80% of companies which fabricate electronic devices and systems or have electronic systems and machines to the manufacturing process. Mexicali is located in the border with the California State of the United States of America (USA). A study was conducted in indoors of three industrial plants to determine the grade level of deterioration of the electronic control systems (ECS) used in the electronics industry of this city. The results showed that to major air pollution detected by specialized methods, the lifetime of the ECS decrease by the generation of corrosion in their electrical connectors and connections at 75% in winter and 50% in summer for this electrochemical phenomenon.

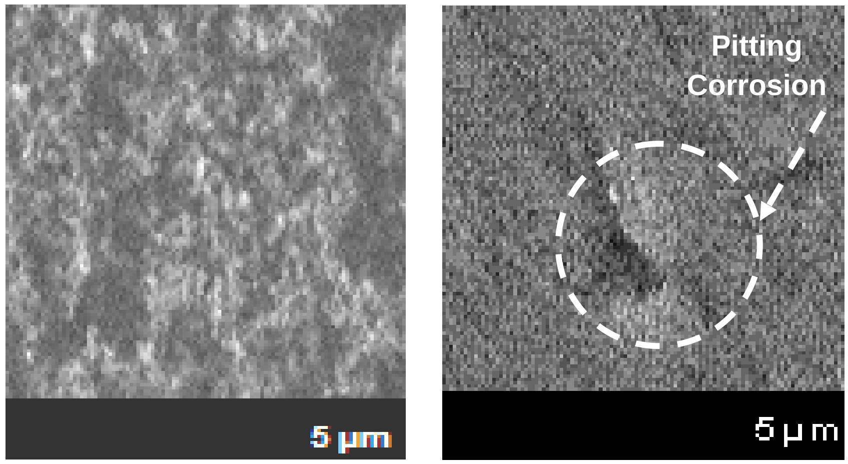
Keywords: Corrosion, electronic devices, control systems, industrial plants

1. Introduction

The permanence of an industrial plant in the world market depends of its planning of the manufacturing, including the methods of the production, specialized people and the ECS used in the industrial equipments and machines [1]. The ECS are very important in the manufacturing process with control operations to assembly parts of a product, detect defects in articles fabricated, count the partial and total products manufactured, make risky operations with toxic chemical, control humidity and temperature that originate the corrosion process, generation of clean environments to avoid the deterioration of the articles fabricated and the ECS, and repair defective articles fabricated, principally. All factors of the functions of ECS are necessary verify in some periods of the day to are sure that the electronic equipments and machine with ECS are operating correctly. The uncontrolled operations mentioned above, can decrease the production yielding and the low the value of the article fabricated, derived by the capacity of the ECS in the industrial process. The damage of the ECS can decrement their functions and reduce their electrical properties, decreasing their lifetime and causing economical losses. This is affected in the major times, by the uncontrolled microclimate of indoor in the industrial plants, causing uncontrolled chemical processes that affect the operation of the ECS [2]. The presence of air pollutants which penetrate by inlets, air conditioning systems and holes, principally; are deposited in the electrical connections and connectors. The corrosion that occurs in industrial plants generates great economic losses, which concern to the owners of companies and managers and specialized people of the electronics industry. Various research institutions works a lot about this phenomena in different methods to know the origin of the different types of corrosion that can occur. The two more One of the principal types of corrosion which occurs in the companies located in Mexicali, are the uniform and pitting corrosion, where the first type of corrosion is detected very easy because appears in the majorly of the metallic surface. The pitting corrosion is more difficult to detect, because in this type are formed corrosion products over the pitting, and its can run at low or fast velocity to into the metal and not outside this, causing the deterioration of the metals of the electrical connectors and connections and therefore the electrical failures [3].

1.1 The global electronics industry

The world market competition, has led to develop technological advances, particularly in the area of the electronics, which are increasingly being manufactured, smaller components, robust and with a greater number of operations. The tendency to miniaturization of technology is a leader in the development of equipment electronics such as cell phones, electronic organizers personal and microcomputers, primarily. Materials used in the electronic components are alloys based on aluminum (integrated circuits with at micro and nano size of wire), copper contacts nickel electro-plated with gold to improve the resistance to corrosion, but increase the cost of this [4]. The characteristics of modern electronic equipment with high voltage contemplate three principal factors as speed of operations, very small currents and the miniaturization and extremely sensitive to corrosive agents. This can lead to some electrical failures in the microelectronic components, generating technical problems in the ECS, caused by the atmospheric pollutants and the variations of humidity and temperature. Its attack the principal metallic materials mentioned above, used in the electronic devices. The microchips are protected by specialized coatings to prevent that not suffer any type of damage immediately by exposure to aggressive environments and climate changes decreasing its functionality and their lifetime. The corrosion damage tolerance of electronic components is very small order of magnitude (10-12 grams, pico-grams). According to research studies, the order of the width of the films of electronic boards is 50 microns. In hybrid circuits (HC), the space should be 2.5 microns. This type of microelectronic devices corroded is showed in the figure 1.



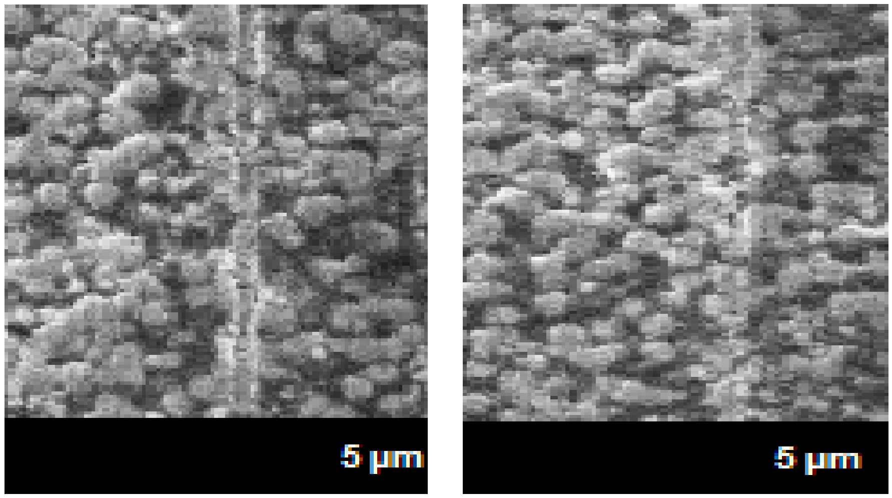
(a) (b)

Fig 1. Microphotographs of metallic surface deteriorate of ECS caused by (a) uniform corrosion and (b) uniform and pitting corrosion in a industrial plant in Mexicali (2011).

As show in the figure 1, the metallic surfaces of the microelectronic devices were damaged by the corrosion process, indicating in each microphotography the presence of uniform corrosion, but in the section b, appeared pitting corrosion with a little pit where not was observed to the naked eye, and only was detected with the microanalysis [5].

1.2 Corrosion in the electronics industry

The electronic boards suffer a variety of problems in their electrical conduction surfaces by the presence of the air pollutants as sulfurs principally and the levels of relative humidity (RH) and temperature. When its parameters are combined, the atmospheric agents react very easy with the metallic surfaces, decreasing the resistance to the corrosion of the connectors and electrical conductive paths. This causes the formation of metallic filaments that grow between routes where not debit growth, causing electrical conductivity between terminals metal (pins), or metallic unions [6]. The conditions required for this type generating a combination of ionic contamination, humidity (> 70%) and temperature (> 30 ° C) and the voltage application. The ECS used in very dry conditions almost not suffer from the corrosion, but at high RH and low in some months of winter and high RH and temperature in some periods of summer temperatures this process, originates the condensation forming visible or invisible thin films of water that occurs on the surface of the metallic connectors and connections, beginning the corrosion. This originates the absorption very fast of the air pollution by the micro and macro electronic components, decreasing the metallic surfaces by the deterioration and for consequence the strength of the material forming metallic dendrites (Figure 2).



(a) (b)

Fig 2. Microphotography of metallic dendrites formed in pathways of electronic devices in (a) summer and (b) winter.

As show in figure 2, in the both microphotographs (a and b), the pathways where flow the electrical current was corroded, indicating that corrosion products cover not totally the metallic surface and causes a pitting corrosion under the corrosion products.

1.3 Atmospheric corrosion

The climatic factors generate the dispersion of air pollutants such as fine particles and gases: hydrogen sulfide, sulfur dioxide, carbon monoxide and nitrogen oxides. This air pollutants, in sometimes exceed the standards of air quality in this region. These contaminants are detected by specialized teams of Environmental Monitoring Stations (EMS) installed in strategic places of the Mexicali city. These chemical agents are emitted by external sources such as traffic, industrial plants, geothermal fields, soil erosion and microorganisms, which penetrate to the indoor of the electronics industry. At levels above 80% of RH and 25°C, that is common in some periods of the year in Mexicali, were obtained the time of wetness (TOW), indicating the periods in which the metal surfaces of electronic devices kept moist for at least one day, causing the electrochemical corrosion process. The pollution levels are evaluated according to standard regulations that indicate the concentration levels regulated by environmental institutions in each country. In Mexico, the Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT), in mutual agreement with the Environmental Protection Agency (EPA) of USA [3, 7], are responsible for the regulation of the pollution emissions of the outdoor and indoor of the industrial plants. With international agreements, on the border of Mexico and the United States, SEMARNAT and the EPA, have installed Environmental Monitoring Stations (EMA) and Meteorological Monitoring

(MMS), to obtain information about the outdoor environment that have effect in the levels of pollution and the variations of the RH and temperature showing diverse values in different seasonal periods. The chemical agents which generate the air pollution penetrate to the indoor of industrial plants, where are monitored principally in this city the hydrogen sulfide (H2S), sulfur dioxide(SO2), carbon monoxide (CO), nitrogen oxides (NOX) and the ozone (O3) and the particulate matter (PM10 and PM2.5), reported by the National Ambient Air Quality Standards (NAAQS, 2006). Additionally are monitored the volatile organic compounds (VOC) generated in indoors of the companies, like ammonia that is inorganic agent and have an effect in the deterioration of metallic connectors and connections of the ECS, and even at low concentrations, have a significant effect on the corrosion phenomenon [2].

1.4 Corrosion types in the electronics industry

According to the humidity originated in indoors of industrial plants, material of electronic devices generates different corrosion processes, such as those explained below [1]:

A). Corrosion voltaic. This type of corrosion is generated in a small space between electronic circuit components, when a voltage is applied to a device generating the voltage gradients in order of mega-volt circulating component surfaces, resulting accelerated electrochemical corrosion reactions and ion migration. The integrated circuits are very susceptible to corrosion. The combination of electrical fields, with atmospheric humidity and air pollution are the main promoters of this type of corrosion in metals used in the microelectronic devices. The corrosion can occur only with the presence of low humidity in sometimes. The pH generated by a cathodic reaction, by reduction of water. High pH levels result in a solution in the passive film the surface of the metal oxide and aluminum substrates and increases driving resistance, generating an open circuit.

B). Electrolytic metal migration. In presence of moisture and an electric field, silver ions migrate to a charged surface cathodically, forming dendrites, which grow as bridges between contacts, possibly causing short circuits to reduce the production yielding of the ECS and decreasing their life time, and in sometimes causing fires. Always a small volume of he dissolved metal forms the dendrites in form large. Other materials which are susceptible to metal migration ions are the gold, tin, lead, palladium and copper. Dendrites can be silver, copper, tin, lead or combination of these metals and cause electrical failures in industrial electronic equipment for short circuits. The dendrite growth can be generates very fast the electrical failures of ECS, and always is known to can be have effect at least after 30 minutes or sometimes up to several days, weeks or months until originates great damage in the electrical connections and connectors. The growth rate of dendrite depends on the applied voltage, the amount of contamination atmospheric combined with the moisture, which affect the metal surface.

C). Formation of pores and cracks in electrical contacts and connections metal. To prevent the connectors and electrical contacts stained by the process of corrosion metals such as gold, the process is performed on the surface of silver contacts and connectors. However, defects in protective coatings of metals can expose and corrode the substrate material and create imperfections like pores and cracks. If the substrate is copper or silver, and it is exposed to environments with sulfates or chlorides, the products corrosion, cracks will generate pores, and if gold added to silver forms a high resistance in the conductive layer, whereby open circuits are generated.

D). Fretting corrosion on separate jacks with fine finishes. It results in the formation of tin oxides boards electronic or electrical contacts. The problem starts very often when the tin is used or replaced by gold metal being a more economical. The possible solution is to replace the hand or use a little more expensive metals.

E). Galvanic corrosion. It occurs when two different metals, such as aluminum and gold come together, as it is in the encapsulation of integrated circuits. The polymers used are packaging as a pair porous and plastic tapes that seal metal joints are manufactured as electronic devices ceramic or metallic. Sometimes, humid environments generate galvanic corrosion conditions.

F). Corrosion in industrial processes. Integrated circuits are environments exposed to numerous aggressive attack ionic or wet and aluminum, which are the main compounds. The ion etching requires a combination of gas and if this is formed as chlorides aluminum covering the metallic structures of the ECS, which are acidic agent and generates acid moisture. The ionic contamination occurs in soldering processes and handling of materials used to fabricate microelectronic devices with very thin films, originated by dust and changes climate.

G). Microcorrosion in the manufacture of integrated circuits. The metallization of aluminum and copper alloys can form inter-metallic compounds like Al_2Cu with a large grain boundaries. This is the beginning of the dissolution of metals which form a micro-pitting during the etching.

H). Corrosion by chlorinated solvents or halogenated. Liquid solvents steam or used in the manufacture of integrated circuits, mainly corroding aluminum components. Contaminated water of solvents increases the time of the presence of corrosion and also increases the corrosion rate, which is the speed at a metal which disintegrates. The stabilized solvent dissolution with alcohol or aromatic solvents is the main cause of halogenated solvents breaking and forming chlorine ions, corroding the aluminum and copper alloys, with major effect in the aluminum.

I). Corrosion in welding. Corrosion resistance joints of tin and lead in aqueous and gaseous environments is a function of the alloy. This significantly improves when increases more than 2 times the rate of the alloy. Lead forms unstable oxide, which reacts readily with chlorides, borates and sulfates.

1.5 Mexicali is an arid region

The topography of the Mexicali city and the levels of air pollutants mentioned above, penetrate to indoor of the electronics industry where there are about 156 industrial plants according to the AMAQ [8]. These contaminants in certain seasonal periods generate aggressive climates mainly in production areas and warehouses where are used and store the microelectronic devices and the ECS. The climate is an important factor, and in the operational functions of the ECS of this city. The RH of the city is around from 50% to 90% and the temperature ranges are near of 0 ° C and the higher value are around the 45 ° C. These climate changes vary the outdoor and indoor of the industrial plants, contributing to the deterioration of materials. Dust and chemicals in indoor environments, are added to the microelectronic components of ECS such as computers, measuring instruments and industrial machinery as showed in the figure 3. A computer operating properly when it is free of contaminants and the microclimates are controlled [9, 10].

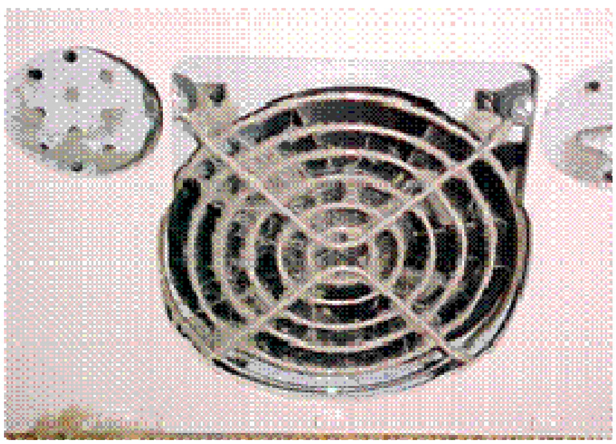


Fig 3. Electric fan controlled by ECS of a industrial machine contaminated by dust and chemical agents

1.6 Mathematical simulation

MATLAB is a software called Matrix Laboratory, being a mathematical software that offers integrated development environment (IDE) with a proprietary programming language. Its basic features are: array manipulation, data representation and functions, implementation of algorithms, creation of user interfaces (GUI) and communication with programs in other languages and other hardware devices [11]. The MATLAB package has two additional tools that expand their services: Simulink and Guide Commands. In this study, this software was used to made correlations about the climatic factors and the air pollutants related to the corrosion rate (CR), which represents the deterioration levels of the materials used in the electrical connectors and connections of the ECS.

2. Methodology

Humidity and temperature are the two most important climatic parameters related to the origination of the corrosion process. For this study was used information of the air pollutants mentioned above, and also the temperature and RH of 2010 to 2011 obtained of the specialized equipments. Based on the statistical information of the climate factors was made an analysis of the generation of the different types of corrosion in the ECS, which use microelectronic devices. According to the emission supplies, the levels of air pollution are concentrated in some areas of Mexicali, principally where are located the electronics industry. In Mexicali the temperature is very hot in summer until major of 45 °C in some periods of this season and very cold nights until near of 0 °C in the winter. The maximum and minimum recorded monthly periods of relative humidity and temperature of indoor show ranges varied be under 10% and above 90% for RH, and temperatures of 0 ° C in the winter to nearly 50 ° C in the months of June to August. The TOW monthly values correspond to low and medium levels of corrosivity, with ISO 9223 and ISO 11844-1 [12, 13, 14]. The study was made in three industrial plants of this city principally of the electronics area from 2010 to 2011.

3. Results

The levels of RH and temperature promote the process and influence the dispersion of air pollutant from natural and anthropogenic sources, causing the corrosion process. In the summer the atmospheric pollution, is based on the temperatures in the range from 30 °C to 42 °C and the RH levels ranging from 55% to 85% with a higher intensity is observed of 90%, representing low dispersion of air pollutants remaining near of the industrial plants and penetrating to its companies. This originates in some periods of the year and some areas, a high concentration of pollutants, increasing the CR and the deterioration of the metallic surfaces of ECS. The improvement of this job is to save costs in the electronics industry which give the opportunity to make the study, for not generate economic losses by the attention of warranty in the periods where the products manufactured in this industrial plant and others with the same production process, and debit be operating in good conditions. Before this study around of 15% of these products were returned to this industry to the warranty.

3.1 Correlation analysis of CR in ECS and climatic and environmental factors

The CR was influenced by the exposition to different levels of the air pollutants mentioned above, damaging the microelectronic devices. In this study a correlation analysis was made to know the grade of deterioration of the micro components of the ECS. At different levels of RH, temperature and concentration levels of air pollution, was obtained diverse values of correlation, indicating the major indices in winter where occur the condensation phenomenon and the fast and easy adherence of the air pollutants, as show the table 1. The decreasing of the ECS in sometimes for the corrosion process, generates low productive yielding and every time the microelectronic devices suffer damage decreasing their lifetime. The correlation was divided in four ranges.

Table 1. Correlation analysis of CR in different seasonal of the year

	Ranges		Ranges			
	T, 0 °C– 20 °C	RH, 0% - 40%	T 21 °C– 35°C	RH, 41% - 75%	36 °C– 45°C	76% - 90%
Spring	0.76	0.78	0.77	0.79	0.79	0.78
Summer	0.82	0.83	0.84	0.86	0.84	0.85
Autumn	0.75	0.74	0.77	0.75	0.76	0.77
Winter	0.89	0.87	0.90	0.90	0.88	0.89

Table 1 shows the levels in each seasonal period where are correlated the climatic factors with the CR. In the spring season, the major CR was 0.79 at the ranges from 36 °C to 45 °C and 0.78 from 76% to 90%. In this season, the presence of corrosion was low, without high effects in the deterioration of metallic surfaces and the lifetime of ECS. The lower value of CR was 0.76 at leveles from 0 °C to 0.78 from 0% to 40%. In summer the higher value of CR was 0.84 at levels from from 36 °C to 45 °C, where was presented pitting corrosion at value higher than 75% and 35 °C, and the CR of 0.85 was the highest value at ranges from 76% to 90%. In autumn was indicated the lowest value of the analysis with 0.75 from 0 C to 20 C and the higher level was a intensity 0.77 of CR at ranges of 21 °C to 35 °C. In this season the corrosion appear at low intensity as same as the spring season. In winter the CR was represented the highest value with 0.90 at ranges from 21 °C to 35 °C and 0.90 at levels from 41% to 75%. In this season was presented uniform corrosion at values higher of 70% and 30 °C. This represented that in winter the metals suffer of more damage than in others periods of the year.

3.2 MatLab simulation

A factor showed in this study was that at low and medium concentrations of air pollutants, the CR was very fast, but at high concentration of air pollution, the CR was low, as mention the standard concentration level to the sulfurs is 75 ppb, according to the EPA. Furthermore, in winter, levels near of 10°C and ranges of RH from 35% to 70%, there was a lower incidence of condensation of water on the metal surface and the CR was high. In the winter time, it has higher air pollution in the temperature range of 2 °C to 13 °C and RH levels from 34% to 70%. At values of temperature from 15 °C to 20 °C and RH of 45%, 75%, the CR was higher. At temperatures of 25 °C to 30 °C, with RH levels from 30% to 75%, there is a low dispersion of air pollutants, showing a CR high and more impact in the deterioration of the metallic surfaces of ECS. The analysis in this research in the summer for the dispersion of air pollutants, indicating that focus on larger scale, at temperatures below 20 °C, showing a CR low at 35% to 55%, being a high dispersion of the air pollutants in indoor of the industrial plants located in

Mexicali. The corrosion was stabilized at 40 °C and was a CR very low as show figures 4 and 5.

In figure 4, the maximum CR of the correlation was 391 mg.m^2/year at 28 °C and 78% temperature and RH levels showed fast deteriorate of the metallic surfaces of the electrical connectors and connections of the ECS. This causes lack of electrical current and not function the ECS, originating damage in some microelectronic components of the ECS and decreasing their lifetime. The minimum CR was 9 mg.m^2/year at 11 °C and 54% temperature and RH levels. In figure 5, the maximum CR was 209 mg.m^2/year at 42 °C and 78% of temperature and RH levels and the minimum value of CR was 6 mg.m^2/year at 19 °C and 58% of temperature and RH levels.

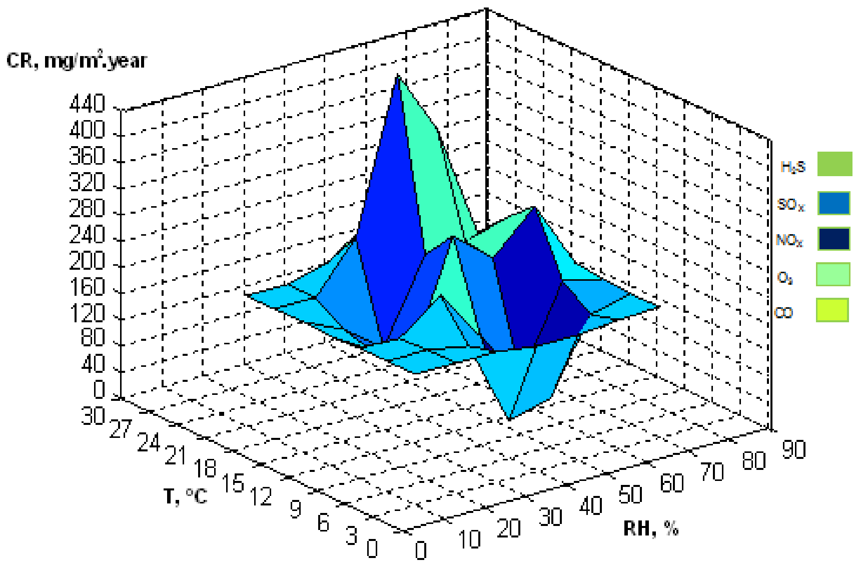


Fig 4. Correlation of CR and climatic factors with air pollutants monitored in Mexicali in winter (2010-2011).

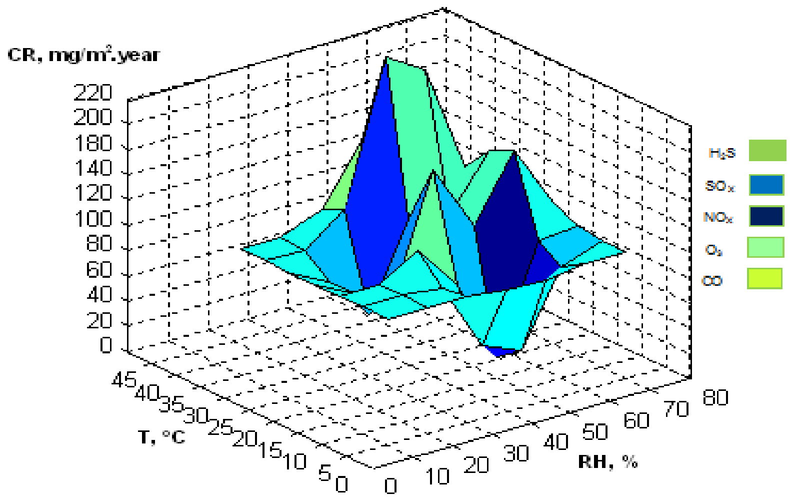


Fig 5. Correlation of CR and climatic factors with air pollutants monitored in Mexicali in summer (2010-2011).

4. Conclusions

With increasing miniaturization of systems electronics and the explosive increase in its availability, it is estimated that the corrosion and deterioration of metal materials electronic will increase causing incalculable consequences. The corrosion phenomena have an effect in the operation of ECS with microelectronic used in the electronics industry. The presence of acidic substances in indoor of industrial plants to damage the electrical connectors and connections of ECS, originates aggressive environments, which generates very fast the deterioration and decrease the lifetime of the ECS of industrial equipments and machines. This affects the functionability every time and originates electrical unoperation that causes the defect before they present their standard lifetime, and begins to fail electrically. This concern to the specialized personas and managers because generates unnecessary costs. The types of corrosion detected in the connections of electronic devices as microchips were the uniform and pitting corrosion, which are generated by the different values of humidity and temperature in the diverse periods of the year. The climatic factor with major effect was the humidity, which was changing in according to the seasonal period. The uniform corrosion was formed in the winter season and the pitting corrosion appeared more frequently in the summer period. This was evaluated to determine the periods of the year, which are a corrosion rate (CR) high in some periods of the year, decreasing the manufacturing process until 70 %.

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