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Influence of Air Pollution Factors on Corrosion of Metal Equipment in Transmission and Transformation Power Stations

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Abstract: In this paper, the atmospheric environmental corrosion grade of substations in 11 prefecture level cities in Shanxi Province is evaluated through a metal hanging sheet experiment. Combined with the main environmental factors, such as temperature, relative humidity, and the concentration of main pollution factors, such as SO_2, Cl^-, dust, etc., the influence of various factors on the corrosion of transmission and transformation equipment is analyzed, and the corresponding anti-corrosion measures are put forward.

Keywords: temperature; humidity; atmospheric corrosion; dust; anticorrosive

1. Introduction

The annual loss of property caused by metal corrosion is about 4% of the gross national product, according to the American Society for Metals, and the annual scrap of metal due to corrosion is 30% of the production. The annual economic loss due to rusting in China is 300 billion yuan, and the loss of the steel is equivalent to the annual output of Baotou Iron and Steel Company. If indirect losses are considered, the total cost of corrosion is estimated to be up to 500 billion yuan, accounting for about 5% of the total output value of the national economy [1].

Atmospheric corrosion is the electrochemical corrosion of metal surfaces under extremely thin liquid films. The corrosion process is a comprehensive and intersecting engineering problem involving a gas phase and liquid phase. The atmospheric environment in different regions is not identical, and the corrosion mechanism, influencing factors, and degrees of corrosion of local transmission and substation equipment are also different. If a single anti-corrosion measure is taken, in different atmospheric corrosion environments, it may lead to unsatisfactory anti-corrosion effects in areas with harsh environments [2], or an increase in the cost of anti-corrosion in some mildly corrosive areas. In order to enhance the corrosion protection effect of Shanxi State Grid transmission and transformation equipment and improve the reliability of power supply of the power grid, it is necessary to carry out research on the corrosion mechanism of the atmospheric environment on power transmission and transformation equipment in accordance with the characteristics of Shanxi's atmospheric environment.

2. Power Transmission and Transformation Metal Materials

A large number of metal materials are used in power transmission and transformation equipment and components. Their main functions can be divided into two categories: One is the bearing role, as structural parts have a support, transmission, tightening function, are generally steel-based, such as transmission towers, have a switchgear operation transmission mechanism, including various types of fastening bolts and steel cores in the wire. The other category plays a role in carrying current, as a conductive function plays the role of transmitting current, most of which are aluminum and copper and their alloys,

such as various aluminum and aluminum alloy strands on transmission lines, conductive rods and tentacles in switchgear, windings and leads in transformers, etc. In this section, several metal materials are selected, such as carbon steel, stainless steel, aluminum and aluminum alloys, copper and copper alloys that are most used in transmission and substation equipment, as shown in Table 1.

Table 1. Introduction of metal materials commonly used in power grids.

Materials	Functions	Grid Equipment
Carbon steel	Mainly under load, with high yield strength and good plasticity, toughness	Transmission towers, substation equipment structures, circuit breaker energy storage springs, transmission mechanism components, etc.
Stainless steel	Good corrosion resistance and containing a certain amount of chromium	Transmission mechanisms of switchgear, terminal box housings, springs, bolts, hoops, etc.
Aluminum, aluminum alloy	Low density, good plasticity, corrosion resistance, and excellent electrical and thermal conductivity	Conductors, equipment clips, busbars, isolator conductive rods, tubular busbars, etc.
Copper, copper alloy	Excellent electrical conductivity	Transformers, busbars, cables, contact pointers for disconnectors, device clips, etc.

3. Investigation of Shanxi Atmospheric Environment

With its abundant coal resources, Shanxi has made significant contributions to the country's industrial construction and was once known as "one of the eight major industrial cities in China". As a large province of coal resources [3], the industrial structure of Shanxi Province is heavy with energy and raw material industry as the main body. Among them, the air pollution in Linfen is more severe, and the sulfur dioxide in Linfen mainly originates from civil loose coal, industrial coal, and pollution generated in the industrial process, reflecting the characteristics of soot-type pollution. The main coal used by residents is medium- and high-sulfur coal, especially the scattered coal combustion of urban village residents, as well as the combustion of coal in small and medium-sized boilers, which is an important cause of the current sulfur dioxide pollution in Linfen. The corrosion effect of sulfur dioxide on the metal equipment of the transmission and substations is more severe, which makes the local atmospheric environmental pollution level in Linfen higher.

In addition, the provincial capital city Taiyuan, as a resource city, is developed by resources. However, with the deterioration of the environment and the transformation and upgrading of the industrial structure, the pollution of this city is becoming more and more severe, mainly with dust pollution, and the main impact of dust on the equipment of the transmission and substations is pollution flash failure, resulting in massive power outages.

4. Influence of Gas Phase Factors on Corrosion

Meteorological factors in the atmosphere directly affect the corrosive effect of the atmosphere, including relative humidity in the atmosphere, metal surface wetting time, air temperature, sunshine time, rainfall, and other factors [4].

4.1. Relative Humidity

From the perspective of corrosion mechanisms, atmospheric corrosion is essentially a chemical or electrochemical reaction of underwater film. The water film condensed by the moisture in the air on the surface of the material is one of the basic conditions for atmospheric corrosion, and the formation of the water film is closely related to the humidity in the atmosphere.

Depending on the degree of moisture on the surface of the corroded metal, atmospheric corrosion can be divided into three categories: Dry atmospheric corrosion, tidal atmospheric

corrosion, and wet atmospheric corrosion [5]. The effect of air humidity on metal corrosion depends on the relative humidity (RH), which refers to the ratio of water vapor pressure in the air to saturated water vapor pressure at the same temperature, generally expressed as a percentage. The effect of relative humidity on the atmospheric corrosion of metal materials is not linear. There is a certain relative humidity value. When the relative humidity of the environment exceeds this value, the corrosion rate of the metal will increase rapidly, and this value is called critical relative humidity. The relative humidity of different metals is different, and commonly used metal materials such as iron it is 65%, in zinc it is 70%, in aluminum it is 76%, and in nickel it is 70%.

Li et al. [6] used the electrochemical impedance spectroscopy (EIS) method to study the atmospheric corrosion behavior of weathering steel in different relative humidities in an experimental simulation environment. The results show that when the RH is greater than 60%, the water molecules adsorbed on the smooth metal surface reach three monolayers, and when the humidity is greater than 70%, the corrosion process begins to occur. The relationship between the thickness of the water film and the corrosion rate is shown in Figure 1 [7].
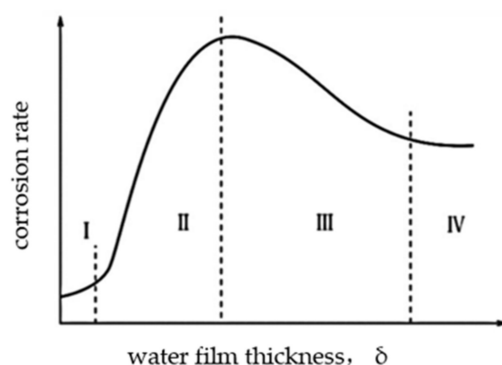

Figure 1. Relationship between atmospheric corrosion rate and metal surface water film thickness [7] I. δ = 1–10 nm II. δ = 10 nm–1 µm III. δ = 1 µm–1 mm IV. δ > 1 mm.

It can be seen that at the beginning, with the increase in the thickness of the water film, a continuous electrolyte film layer is formed, and the oxygen is more easily diffused into the interface, and the metal corrosion rate increases rapidly. However, as the surface water film continues to thicken, the process of oxygen diffusion through the liquid film to the interface is blocked, and the reaction rate gradually decreases, and when the liquid film thickness is greater than 1 mm, it is equivalent to the corrosion of full immersion in the electrolyte, and the corrosion rate is basically unchanged. At the beginning, because the surface liquid film is very thin, oxygen can easily reach the metal surface, and the equilibrium potential of oxygen is more positive than the equilibrium potential of hydrogen, so the depolarization corrosion of oxygen occurs first in the aerobic solution. The reaction of the cathodic process is as follows:

In neutral or alkaline media:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-. \tag{1}$$
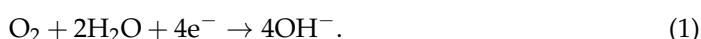
In acidic media such as acid rain:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O. \tag{2}$$

The anode process of corrosion is the process of dissolution of the metal as an anode, the loss of electrons, and, under the condition of atmospheric corrosion, the reaction of the anode process is:

$$M \rightarrow M^{n+} + ne^-. \tag{3}$$

Guo et al. [8] studied the effects of relative humidity changes on stainless steel pitting under $MgCl_2$ droplets by in situ X-ray microtomography and optical microscopy. It was found that relative humidity fluctuations (between 12% and 33% or between 33% and 85%) can lead to many small pit nuclei, while continuous exposure below a constant 33% leads to the growth of individual pits. This conclusion shows that changes and fluctuations in relative humidity affect the formation process of metal corrosion morphology.

4.2. The Temperature

Temperature is also considered an important factor in corrosion in temperate climate zones [9]. The ambient temperature and its changes affect the condensation of water vapor on the surface of the metal, the solubility of various corrosive gases and salts in the water film, the resistance of the water film, and the reaction rate of the cathode and anode processes in the corrosion battery. On the one hand, according to the Arrhenius formula:

$$k = A \exp(-\frac{E_a}{RT}), \tag{4}$$

where k is the rate constant, R is the molar gas constant, T is the thermodynamic temperature, E_a is the apparent activation energy, and A is the frequency factor.

Increasing temperature speeds up the rate of anode reaction, which in turn accelerates corrosion. On the other hand, the increase in the greenhouse will also affect the thickness of the liquid film on the surface of the metal and reduce the relative humidity.

Considering the influence of temperature and atmospheric relative humidity, when the relative humidity is lower than the critical relative humidity of metals, the influence of temperature on atmospheric corrosion is very small, but when the relative humidity reaches the critical humidity of metals, the influence of temperature is obvious. Violent changes in temperature also affect atmospheric corrosion, when the temperature difference between day and night is too large and, coupled with suitable humidity, the water vapor in the atmosphere will condense on the metal surface. Xu et al. [10] have shown that surface condensation is an important feature of the initial stage of atmospheric corrosion of metals, and changes in temperature will promote this process. It follows that the key factor in atmospheric corrosion of metals and alloys is the combined effect of temperature–humidity.

5. The Effect of Atmospheric Pollutants on Corrosion

Atmospheric pollutants are mainly composed of gases containing elements S, C, and N, as well as other solid particles. It is generally believed that the main components of atmospheric pollutants are shown in Table 2 [11].

Table 2. Main components of air pollution.

Gas	Solid
Sulfur-containing compounds: SO_2, SO_3, H_2S	Fine particles such as dust
Chlorine and chlorine-containing compounds: Cl_2, HCl, HClO	Inorganic salts NaCl, NH_4Cl, $(NH_4)_2SO_4$, $CaCO_3$
Nitrogen-containing compounds: NO, NO_2, NH_3	Metal oxide powder Al_2O_3, ZnO
Carbon-containing compounds: CO, CO_2	Carbon and carbon compounds

Atmospheric pollutants are extremely important for the corrosion of metals, such as harmful gases in the atmosphere and solid particulate matter, etc. Sulfur oxide SO_x is the most seriously affected in gases, especially SO_2, which is very high in the atmosphere of cities or industrial areas. The composition of solid particles is more complex, among which those with a more severe impact on corrosion are chloride-containing particles, soluble and corrosive dust particles such as ammonium salts, and particles that can adsorb corrosive substances, such as carbon particles.

5.1. Cl⁻

Chloride ions in sea salt particles are highly penetrating and can easily penetrate the matrix through corrosion products on metal surfaces [12]. In the early stages of corrosion, due to the presence of chloride (NaCl), moisture absorption is very strong, the surface of the steel quickly absorbs moisture from the humid atmosphere, and quickly forms countless corrosive microcells, resulting in enhanced conductivity in the thin liquid film. Salt is the core to absorb water and, with the formation of saturated solution, begins to corrode a small area as the reaction progresses. Na^+, Fe^{2+} move to the cathode region and OH^-, Cl^- move to the anode dissolution region, generating $Fe(OH)_2$ near the active anode region. The weak point of the $Fe(OH)_2$ membrane ruptures, and the outflow of electrolyte forms a "head" outside the original corrosion point, which in turn causes corrosion, and a series of processes (rupture–corrosion–film formation) are repeated countless times to form a continuous filament. However, the $Fe(OH)_2$ corrosion product film is not stable, it decomposes into FeO or gradually oxidizes with O_2 dissolved in the thin liquid film to FeOOH (Equations (5) and (6)):

$$Fe(OH)_2 \rightarrow FeO + H_2O, \tag{5}$$

$$2Fe(OH)_2 + \frac{1}{2}O_2 \rightarrow 2FeOOH + H_2O. \tag{6}$$
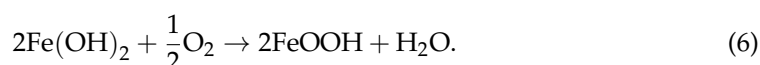
Meanwhile, some FeOOH gradually sheds water to form a more stable insoluble substance—Fe_2O_3:

$$2FeOOH \rightarrow Fe_2O_3 + H_2O. \tag{7}$$

In addition, $Fe(OH)_2$ is slowly oxidized to Fe_3O_4:

$$3Fe(OH)_2 + \frac{1}{2}O_2 \rightarrow Fe_3O_4 + 3H_2O. \tag{8}$$
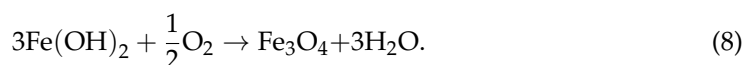
Due to the strong erosive nature of Cl^-, it not only acts as a conductive medium, but also destroys the protective film on the metal surface at the same time as the reactions occur. This process can be described by the following mechanism:
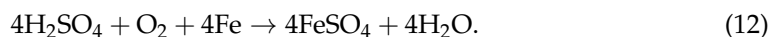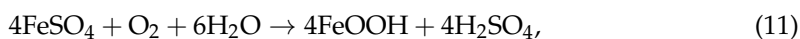
$$Fe(OH)_2 + Cl^- \rightarrow FeOH^+ + Cl^- + OH^-. \tag{9}$$
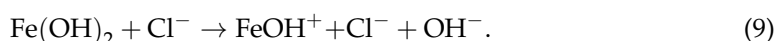
According to the above chemical reaction equation, during atmospheric corrosion, Cl^- causes local dissolution of $Fe(OH)_2$. This leads to the appearance of a fine crack in the dense oxide film through which the corrosive medium penetrates into the matrix, promoting the continuous extension and development of the filament, thereby accelerating the corrosion of the matrix [13]. However, as corrosion progresses, the β formed in the inner layer FeOOH gradually decreases and is converted to Fe_2O_3 during the wet and dry cycle. The generation of insoluble Fe_2O_3 effectively protects the matrix and inhibits corrosion [14].

5.2. SO₂

At present, the mechanism of SO_2 accelerating the corrosion rate of metals has two main causes. First, due to the thickening of the water film condensation, SO_2 participates in the anode depolarization under high humidity conditions. This effect is significantly increased when the SO_2 content is greater than 0.5%. Although the content of SO_2 in the atmosphere is very low, its solubility in solution is about 1300 times higher than that of oxygen, which has a great impact on corrosion. The second is that a part of SO_2 is adsorbed on metal surfaces (such as iron) and reacts with iron to form soluble ferrous sulfate. Further oxidation of ferrous sulfate and formation of sulfate due to strong hydrolysis occur. Sulfuric acid reacts with iron, and the whole process has the characteristics of a self-catalytic reaction. The reaction is as follows:

$$Fe + SO_2 + O_2 \rightarrow FeSO_4, \tag{10}$$

$$4FeSO_4 + O_2 + 6H_2O \rightarrow 4FeOOH + 4H_2SO_4, \tag{11}$$

$$4H_2SO_4 + O_2 + 4Fe \rightarrow 4FeSO_4 + 4H_2O. \tag{12}$$

Metals such as iron and zinc form soluble sulfate compounds in SO_2 atmospheres, and their corrosion rates are linear with SO_2 content [15]. In addition, the corrosive effect of SO_2 on metals is also affected by temperature, and the temperature rise intensifies the corrosion process of SO_2 on metals.

5.3. Solid Deposits

The composition of solid particles is more complex as, in addition to sea salt particles, there are carbon and carbon compounds, nitrates, metal oxides, sand, etc. Ammonium salt particles are inherently soluble and corrosive, and when they dissolve in a liquid film to become a corrosive medium, they increase the corrosion rate. Under the same conditions, NH_4Cl has the most obvious corrosion acceleration effect on Q235 steel compared with NaCl, $(NH_4)_2SO_4$, Na_2SO_4. This is because the chloride ion radius is smaller than the sulfate ion radius, which more easily penetrates the matrix of Q235 steel. Moreover, ammonium chloride easily absorbs moisture and undergoes hydrolysis, producing strong acidity and promoting the dissolution of steel. Although the carbon particle itself is non-corrosive and does not dissolve, it can adsorb corrosive substances, and when the corrosive substances are dissolved in the water film, it can promote the corrosion process. There are also some dusts that are inherently non-corrosive and adsorbent, but can form crevices with the metal surface when they fall on the metal surface. These crevices can increase the condensation of water vapor, which in turn promotes the formation of an electrolyte film on the metal surface. At the same time, this will affect the size of the air contact opportunity at the interface, forming a local oxygen concentration difference, causing crevice corrosion, and accelerating the corrosion of the metal [16]. Considered comprehensively, the ammonium salts with strong water absorption in solid sediments may bind chloride ions and accelerate the corrosion of metals.

6. Study on the Influence of Shanxi Atmospheric Environment on Corrosion of Power Transmission and Transformation Metal Equipment

In this study, the hanging experiment is carried out in 11 cities and nearly one hundred 220 KV substations in Taiyuan, Yuncheng, Linfen, Jincheng, Changzhi, Lüliang, Jinzhong, Xinzhou, Datong, Shuozhou, and Yangquan in Shanxi. The metal materials of the hanging sheet include galvanized steel and carbon steel. After 380–420 days of hanging tablet experiments, the hanging sample was pickled to obtain the weight after pickling, and then the corrosion rate was calculated. The corrosion rates of each locality were compared and analyzed according to the data of environmental factors such as temperature, humidity, SO_2 concentration, cl- deposition rate, etc., and the relationship was explored.

6.1. Corrosion of Hanging Sheets in Shanxi Substation

The hanging plate experiment was carried out near the selected substation, the hanging plate size was $150 \times 100 \times 4$ mm, and each group of 3 pieces was parallel sampled. The original weight of the specimen w_0 was recorded. The experimental apparatus is shown in Figure 2. After a test of about a year, the hanging piece was retrieved and the corrosion loss measurement was performed on the hanging piece. The descaling for measuring corrosion quality loss was carried out with reference to GB/T16545-1996 "Corrosion of metals and alloys—Removal of corrosion products from corrosion test specimens".

Using 500 mL of concentrated hydrochloric acid +500 mL of distilled water +3.5 g of six times methenamine rust removal solution, the specimen was soaked at room temperature, ultrasonicated, and brushed for 10 min, until the rust was removed. At the same time, the corrosion of the descaling liquid on the matrix was corrected by uncorroded steel samples. The rust-removed specimen was washed, dehydrated with absolute ethanol, blown dry and placed in a dryer, and taken out and weighed after 24 h. In each group, 3 parallel

specimens were used to determine the corrosion quality loss value. The corrosion quality loss rate is calculated as follows:

$$v = \frac{(w_0 - w_t)}{St} \tag{13}$$

where v is the corrosion quality loss rate, the unit is g/cm²·a. w_0 represents the original weight of the specimen, the unit is g. w_t represents the weight of the specimen after rust removal, the unit is g. S is the corrosion area of the specimen, the unit is cm². t is the exposure time, the unit is a.

The corrosion thickness loss rate is calculated as follows:

$$R = \frac{(w_0 - w_t) \times 10^3}{S\rho t} \tag{14}$$

where R is the corrosion loss thickness rate, the unit is mm/a; S is the corrosion area of the specimen, the unit is cm²; ρ is the density of the metal, the unit is g/cm³; t is the exposure time, the unit is a.

Figure 2. Diagram of hanging plate experimental device.

Through the above method, the corrosion rate of each city is measured, and the specific data are shown in Table 3.

According to GB/T19292.2-2018 "Corrosion of metal and alloys—Corrosivity of atmospheres—Part 2: Guiding values for the corrosivity categories", the atmospheric corrosiveness grades (C1–CX) of each region can be determined according to the corrosion rate of standard metals (carbon steel, zinc, copper). Table 4 shows the correspondence between the atmospheric corrosion level and the standard specimen corrosion rate.

According to the data of Tables 3 and 4, 6 of the 11 Shanxi cities are in the C3 level atmospheric environment, 4 are in the C4 level atmospheric environment, and 1 is in the C5 level atmospheric environment. From the corrosion hanging film experiment, it can be seen that the overall air pollution level of Shanxi city is medium to high, of which Linfen has the most serious corrosion and is at the C5 level.

Table 3. Average corrosion rate of samples from experimental cities in Shanxi.

City	Material	Average Corrosion Rate (µm/a)
Taiyuan	Galvanized steel	0.3
	Carbon steel	13.387
Yuncheng	Galvanized steel	0.161
	Carbon steel	18.502
Linfen	Galvanized steel	0.378
	Carbon steel	49.274
Jincheng	Galvanized steel	0.403
	Carbon steel	16.405
Changzhi	Galvanized steel	0.215
	Carbon steel	16.703
Lüliang	Galvanized steel	0.41
	Carbon steel	18.991
Jinzhong	Galvanized steel	0.221
	Carbon steel	17.657
Xinzhou	Galvanized steel	0.263
	Carbon steel	12.824
Datong	Galvanized steel	0.738
	Carbon steel	11.335
Shuozhou	Galvanized steel	0.426
	Carbon steel	11.851
Yangquan	Galvanized steel	0.22
	Carbon steel	21.618

Table 4. Corrosion rates of standard metals with different corrosion grades.

Atmospheric Corrosion Rating		Carbon Steel	Zinc	Copper
	C1	$r \leq 0.4$	$r \leq 0.07$	$r \leq 0.05$
	C2	$0.4 < r \leq 8.3$	$0.07 < r \leq 0.5$	$0.05 < r \leq 0.3$
Rate of metal	C3	$8.3 < r \leq 17$	$0.5 < r \leq 1.4$	$0.3 < r \leq 0.6$
corrosion (µm/a)	C4	$17 < r \leq 27$	$1.4 < r \leq 2.7$	$0.6 < r \leq 1.3$
	C5	$27 < r \leq 67$	$2.7 < r \leq 5.5$	$1.3 < r \leq 2.6$
	C6	$67 < r \leq 233$	$5.5 < r \leq 16$	$2.6 < r \leq 4.6$

6.2. Monitoring Results of Atmospheric Corrosion Environment of Shanxi Power Grid

The monitoring of the atmospheric corrosion environment of the above 11 cities includes: The annual average temperature of the atmospheric environment, the annual rainfall, the annual average sulfur dioxide concentration, and the annual average chloride ion deposition rate. Among them, the annual average temperature, relative humidity, and annual rainfall data of the atmospheric environment are from the Shanxi Meteorological Bureau [17], and the sulfur dioxide concentration is from the Department of Ecology and Environment of Shanxi Province [18]. The chloride ion deposition rate is determined in accordance with the standard GB/T19292.3-2018 with a chloride ion monitoring device, the atmospheric environment data are accurate to the municipal level, and the monitoring data are shown in Table 5.

Table 5. Atmospheric corrosion monitoring data of 11 cities in Shanxi Province.

City	Atmospheric Corrosion Rating	Average Temperature (°C)	Relative Humidity (%)	Average Concentration of SO_2 (μg/m³)	Deposition Rate Cl^- (mg/m²/d)
Taiyuan	C3	15	47	22	0.37
Yuncheng	C4	16	48	15	0.45
Linfen	C5	17	38	28	0.84
Jincheng	C3	12	49	16	0.92
Changzhi	C3	13	47	16	0.82
Lüliang	C4	11	43	29	0.31
Jinzhong	C4	14	39	26	0.24
Xinzhou	C3	12	42	29	0.52
Datong	C3	10	42	30	0.51
Shuozhou	C3	9	45	31	0.45
Yangquan	C4	12	43	23	0.42

Date from Shanxi Meteorological Bureau and Department of Ecology and Environment of Shanxi Province.

According to the relative humidity and rainfall, the atmospheric environment can be divided into different types, such as dry type (RH < 60%), ordinary type (RH 60~75%), and wet type (RH > 75%). These cities are all dry type and the coupon test was a one-year short-term test. The climate factor of relative humidity has little effect on the corrosion of carbon steel. When the humidity in the atmosphere reaches 60%, the surface of carbon steel will be corroded slowly and, when the humidity reaches 80–100%, the main factor of corrosion is air pollution [19].

These 11 cities all belong to a typical industrial atmospheric environment. At the initial stage of atmospheric corrosion, SO_2, Cl^-, and other pollutants have a great impact on the corrosion of carbon steel. According to the calculation of a carbon steel corrosion rate prediction equation [20], the sum of SO_2 and Cl^- air pollutant concentrations in Linfen city is the highest, so the corrosion grade is the highest. When the temperature is less than or equal to 10 °C, the temperature does not promote or even hinders SO_2 corrosion. Therefore, although the SO_2 concentrations in Datong city and Shuozhou city are the highest, the corrosion grade is low.

Combined with the concentration of major pollutants in Shanxi cities this year and the year-on-year change rate, as shown in Table 6, according to the Ambient Air Quality Standards [21], the PM2.5 standard is an annual average concentration of 35 and the PM10 standard is an annual average concentration of 70. The PM2.5 in Shanxi Province exceeded the standard by 0.37 times, the PM10 exceeded the standard by 0.33 times, and the concentrations of the remaining two pollutants reached the standard. It can be found that Linfen, Jincheng, and Taiyuan exceed the standard in PM2.5 and PM10 concentrations. The main components of PM particulate pollutants in Shanxi are heavy metals (Zn, Pb, As, Cd, Cu), water-soluble inorganic ions (SO_4^{2-}, NO^{3-}, NH^{4+}), and carbon particles. However, Linfen's chloride ion deposition rate and average annual temperature are higher than those of the other two cities, and such solid deposits can absorb water, making it easier for the metal surface to reach the relative critical humidity to form a water film. In turn, it promotes the formation of water film in an environment with low relative humidity. Coupled with the combined effect of chloride ions and temperature, the corrosion of the metal is accelerated, resulting in the highest atmospheric corrosion level. This conclusion explains the corrosion situation in Shanxi cities very well.

Table 6. Concentration of main pollutants in 11 cities of Shanxi Province.

City	Corrosion Grade	SO_2 Average Concentration	NO_2 Average Concentration	PM10 Average Concentration	PM2.5 Average Concentration
Taiyuan	C3	22	50	107	56
Datong	C3	30	34	73	32
Yangquan	C4	23	42	88	51
Changzhi	C3	16	34	84	47
Jincheng	C3	16	38	111	54
Shuozhou	C3	31	34	100	39
Jinzhong	C4	26	41	86	45
Yuncheng	C4	15	28	100	61
Xinzhou	C3	29	43	79	41
Linfen	C5	28	39	103	62
Lüliang	C4	29	45	87	39
minimum value		15	28	73	32
maximum value		31	50	111	62
average value		24	39	93	48

Concentration unit: $\mu g/m^3$.

7. Summary

Therefore, through the above analysis, in the scope of Shanxi, the main pollutants are particulate pollutants. Although the overall relative humidity is not high, because the metal surface is attached to more solid particles, it is easier for the metal surface to reach critical relative humidity. The deposition rate of chloride ions has a greater impact. Chloride ions have a small ionic radius, which can easily diffuse and contact the matrix at the defect of the oxide film on the surface of the material, causing corrosion. After atmospheric corrosion occurs, the increase in temperature is particularly important for the impact of the corrosion process.

For the atmospheric environment of Shanxi, the corrosion situation can be effectively alleviated by using galvanized steel materials. According to the comparison of the experimental data of galvanized steel and carbon steel hanging sheets in Table 3, the anti-corrosion effect of galvanized steel is obvious. In addition, for heavily polluted areas, the sediment on key metal parts of the power grid ought to be cleaned regularly to avoid the acceleration of metal corrosion caused by sediments.

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