CHEMICAL ENGINEERING TRANSACTIONS
VOL. 71, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216
DOI: 10.3303/CET1871120

Estimation of Economic Loss from Acid Deposition Based on Damage Function

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The destruction of materials exposed to atmospheric acid is an important part of the economic loss of acid deposition. In this paper, by analyzing the mechanism of material damage caused by acid deposition and referring to the damage function at home and abroad, the investigation method of outdoor material stock is put forward, and the economic loss of material damage is estimated by the analytical method estimation model, which provides a reference for estimating the latest economic loss of Atmospheric Acid deposition. The destruction of materials by acid deposition in the atmosphere is an important part of the economic loss of acid deposition. By estimating the acid rain area in South China, it is proved that the destruction of materials by acid deposition has a serious impact on the economy, and the damage of materials is calculated. The calculating method of material loss is briefly described. The economic loss of building materials is estimated by using material damage function and material life formula. The damage effect of acid deposition is quantified.

1. Introduction

Air pollution will cause great damage to materials and buildings. China has invested a huge sum of anti-corrosion costs for pollution abatement every year. Atmospheric acid deposition accelerates and promotes the corrosion on the metallic and non-metallic materials, resulting in serious economic losses. In this context, it is a hot topic about what are the economic losses caused by corrosion and destruction of atmospheric pollutants on the materials (Tezuka et al., 2014; Ana et al., 2015; Garrelts and Lange, 2011). Atmospheric acid deposition has seriously destroyed the environment. It has aroused more and more concern since the economic loss caused by its damage to the materials is huge, which has an impact on China's economy.

In the 1980s, it was estimated whether there was the economic loss caused by damage of peracid deposition to materials in China, but only in some provinces in the south at that time. There were few studies on this facet in the following more than a decade (Tatano and Tsuchiya, 2008; Lee et al., 2014; Shao and Tiong, 2015). Based on the previous studies, this paper explores how to survey the inventory of exposed materials and how to estimate the economic losses caused by this phenomenon. It is also estimated what is the economic loss in the acid rain area. On this basis, we use the extrapolation to estimate it countrywide (Meroni et al., 2017). In this paper, based on the mechanism that acid deposition destroys materials, with reference to the damage function at home and abroad, the survey methods for outdoor material inventory are proposed. The analytical method is used to estimate the economic loss of material damage, in order to provide the clues to estimating the latest economic losses triggered by atmospheric acid deposition. Specifically, By estimating the acid rain area in South China, it is proved that the destruction of materials by acid deposition has a serious impact on the economy, and the damage of materials is calculated. The calculating method of material loss is briefly described. The economic loss of building materials is estimated by using material damage function and material life formula. The damage effect of acid deposition is quantified.

Please cite this article as: Xu Z., 2018, Estimation of economic loss from acid deposition based on damage function, Chemical Engineering Transactions, 71, 715-720 DOI:10.3303/CET1871120

2. An Overview of the Economic Losses of Acid Deposition on Material Damage

2.1 Concept of acid deposition

Atmospheric acid deposition means that the acidic materials in the atmosphere (mainly SO_2, NO, H_2SO_4, HNO_3 and particulate matter) fall upon the underlying surface (surface) in both dry and wet forms. Since rainfall is the primary form of precipitation, intuitive and easy to observe, the acid precipitation is often referred to as acid rain in the literature. The atmospheric acid deposition manifested by the precipitation process is called wet deposition. In addition to rainfall, the atmospheric acid precipitation also includes snow, fog, dew, hail, etc. (Nour et al., 2013). While the atmospheric acid depositions represented by gas diffusion and the falling of solid particles are called dry deposition, and mainly in the forms of sulfur dioxide (SO_2), nitrogen oxides (NOx), chlorine compounds (HCl), aerosols and the like. The specific forms of atmospheric acid deposition are shown in Table 1.

Table 1: The form of atmospheric acid deposition

Type	Phase state	The form of settlement
Dry settlement	Gaseous state	Gas: SO2, NOx, HCl
	Solid state	Aerosol and dust
Wet settlement	Liquid state	Rain, fog and dew
	Solid state	Snow, frost and hail

2.2 The damage function

The damage function relationship, i.e. the metering function relationship (DRF), expresses the destruction effect of various factors on the materials, and links the corrosion rate of the material with the acid deposition pollution level. It is an important basis for analyzing and calculating the economic loss caused by material damages. (Zhang et al., 2016). There are damage (metering function relationship) and lifetime functions available for the materials, which are used in the first and the most important step for economic estimation. This chapter lists the results from studies on damage function relationships in recent years at home and abroad. These formulas can be directly applied under certain conditions in some areas (Choi and Cho, 2016).
Wang Zhenyao and Zheng Yiping from the Institute of Metal Corrosion and Protection, Chinese Academy of Sciences have surveyed the effects of acid rain on metal corrosion in the southwest China. They exposed the materials to the atmosphere to absorb SO_2, and made a linear-regression analysis on the annual corrosion rate of each material and the annual average of SO_2 sedimentation rate. The regression equation and correlation coefficient are available as shown in Table 2:

Table 2: Damage function of several metals

Material and brand	Period of exposure (year)	Regression equation	Correlation coefficient(Y)
Carbon steel A3	1	W=623+7.6SO2	0.8
	2	W=876+14.3SO2	0.7
Zinc Zn-2	1	W=10.66+0.248SO2	0.99
	2	W=15.3+0.428SO2	0.97
Aluminum L4	1	W=0.595+0.036SO2	0.66
	2	Y=0.981+0.035SO2	0.65
Copper T2	1	W=25.6+0.274SO2	1
	2	W=35.2+0.482SO2	0.93
Weatherproof steel	1	W=287+1.67SO2	0.92
10CrNiCuP	2	W=418+2.36SO2	0.91

W for metal corrosion weightlessness (g/m2* year);
SO2 is the sedimentation rate of SO2 (mg/m2*day).

These regression equations only include the effects of SO_2 rather than H^+ and other air pollutants, but they can reflect the quantitative relation of material damage within the limits, so as to provide the clues to the investigation on the corrosive damage to the materials in other provinces and cities in China. Wang Wenxing and Hong Shaoxian from the Chinese Research Academy of Environmental Sciences have also conducted the survey in this field in the Guangdong and Guangxi. The material exposure test in the indoor simulation environment builds a binary regression function relationship with five representative materials by changing two major factors and in contrast with the field material exposure test, as shown in the following formula:

Steel A_3:

$$Y = 39.28 + 81.41[SO_2] + 21.20 \times 10^4 \left[H^+\right] \quad (1)$$

Galvanized steel:

$$Y = 0.43 + 4.47[SO_2] + 0.95 \times 10^4 \left[H^+\right] \quad (2)$$

Paint film steel:

$$Y = 5.61 + 2.84[SO_2] + 0.74 \times 10^4 \left[H^+\right] \quad (3)$$

Aluminum:

$$Y = 0.14 + 0.98[SO_2] + 0.04 \times 10^4 \left[H^+\right] \quad (4)$$

Marble:

$$Y = 14.53 + 23.8[SO_2] + 3.8 \times 10^4 \left[H^+\right] \quad (5)$$

In the above formulas:

Y -- Material corrosion rate, $\mu m / year$;

$[SO_2]$ --Concentration of SO_2, mg / m^3;

$\left[H^+\right]$ ---Concentration of $\left[H^+\right]$, mol / l.

These regression equations are more applicable to the situation in the south China where there is more acid rain, so that H^+ is a major factor that cannot be ignored.

3. Estimation of Economic Loss Caused by Material Damage

3.1 Estimation and calculation on economic losses

The comparative and the analytical methods have their respective strengths, but the former is more direct and definite. In fact, the object as required in the survey is difficult to pick out, and there is a heavy load for the survey. It is only applicable to estimate the economic losses in local areas and small areas; while the analytical method is fit for the estimation of economic losses in a large area, but it requires reliable and practical material damage function and more accurate material in-service life, the geographical distribution and regional distribution data for pollution level, so that it is rather difficult (Zhuang et al., 2016; Balasubramanian et al., 2016). This study proposes a set of the estimation methods applicable to the economic losses in a large area, which belongs to the analytical method.

Currently, there are many estimation methods in the world, and the more applicable mode is:

$$K_a = K \cdot S \cdot \left(L_p^{-1} - L_0^{-1}\right) \quad (6)$$

Where:

K_a is the economic loss caused by material destruction due to acid deposition every year, Yuan;

K is the repair or replacement cost per unit surface area of the material, Yuan / m^2

S is the surface area of the material, m^2

L_p is the material service life under acid deposition conditions, year;

L_0 is the material service life under acid-free deposition conditions, year.

The estimation of economic losses caused by material damage due to acid deposition includes the following steps:

Step 1: Estimate the range of materials;

Step 2: Select pollution factors and loss functions;

Step 3: Solve the service life of the material;
Step 4: Distribute the materials in different polluted areas;
Step 5: Solve K, S and Ka.
Refer to Fig. 1 for specific procedure.

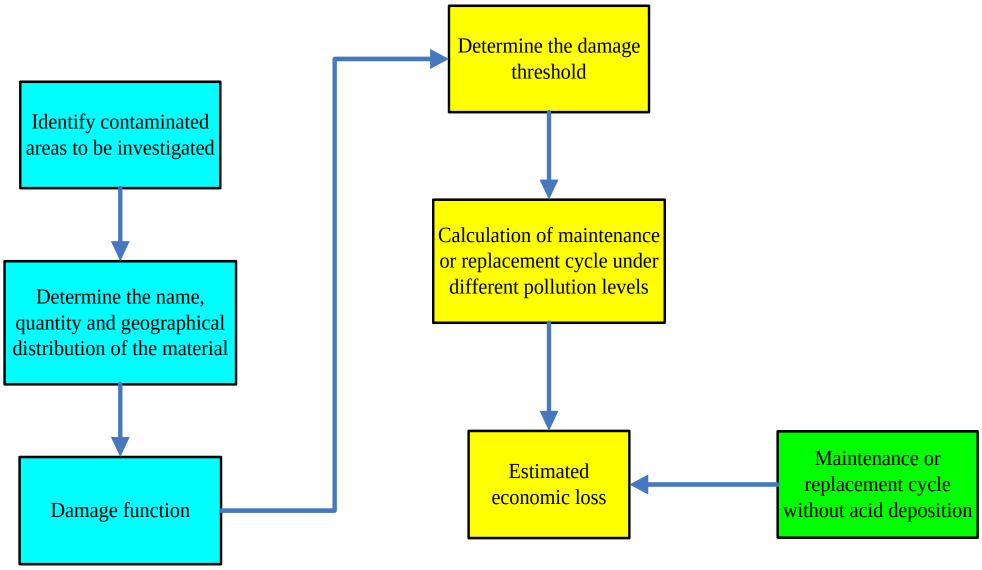

Figure 1: Steps of material loss calculation

3.2 Economic estimation on material loss in acid rain zone

The frequency of acid rain in most areas in the south of the Yangtze River is greater than 50%. The frequency of annual acid rain in Zhejiang, Jiangxi, Hunan, Guangxi, Chongqing, and Guizhou is more than 80%. In this section, we focus on estimating the material losses in these provinces on the basis of Guangzhou's estimation.
Due to time and overhead limits, it is not possible to conduct a complete survey on the materials in the acid rain zone.
The distribution of pH value in the southern provinces, the pH value in Zhejiang is mostly around 4.5, Jiangxi is about 4.5, Hunan is about 4.5, Guangdong is about 4.5, Guangxi is about 4.5, Guizhou is mostly about 4.0, and Chongqing is 4.0 or so. For the distribution of SO_2 concentration, the average concentration in national control network cities of each province is used as the concentration value of the province. It is calculated that SO2 concentration is 0.051 mg/m3 in Zhejiang, 0.030 mg/m3 in Guangdong, 0.064 mg/m3 in Guangxi, 0.031 mg/m3 in Jiangxi, 0.067 mg/m3 in Guizhou, 0. 10 mg/m3 in Hunan, and it is 0.108 mg/m3 in Chongqing. Analyze it by the formula given above, it can be calculated that the economic losses of material damage in the acid rain zone of provinces are shown in Table 3:

Table 3: Economic estimation of material loss in various provinces of acid rain area

	Zhejiang	Jiangxi	Hunan	Guangdong	Guangxi	Guizhou	Chongqing
Cement	681.78	612.98	897.23	1021.96	579.78	487.86	437.12
Brick	2356.25	2186.34	2826.33	3417.43	2297.69	1064.97	936.7
Brick+ Cement	216.35	282.84	379.86	473.35	297.48	259.93	239.78
Wood	757.42	942.86	2413.7	2865.82	1013.89	2525.15	2457.83
Marble	5157.82	31.54.17	9794.99	7247.39	5666.76	8478.12	8655.3
Granite	3642.12	3742..84	8898.94	6614.93	5196.22	7718.82	7877.74
Cement + Stone	9373.84	6894.73	27969.67	23194.94	9925.2	25344.95	25639.53
Paint	4172.49	2296.53	5328.27	6791.98	3933.86	5688.97	5469.99
Tile	54.52	49.29	61.92	91.52	52.48	44.36	39.89
Steel	64261.9	49569.32	215744.7	89264.42	67729.16	99312.6	10232.83

Note: The materials in Guangdong are derived from those in Guangzhou. Assume the per capita ownership of materials in the provinces of south China is constant, the quantity of materials of individual province will be inferred from this figure in Guangzhou. Based on the figure that the total ownership of cars is 2.394 million in Guangzhou, per capita ownership is then 0.41. Assume that the per capita ownership of bicycles in each province are equivalent to those in Guangzhou, the total number of bicycles in each province can be derived from the population of each province.

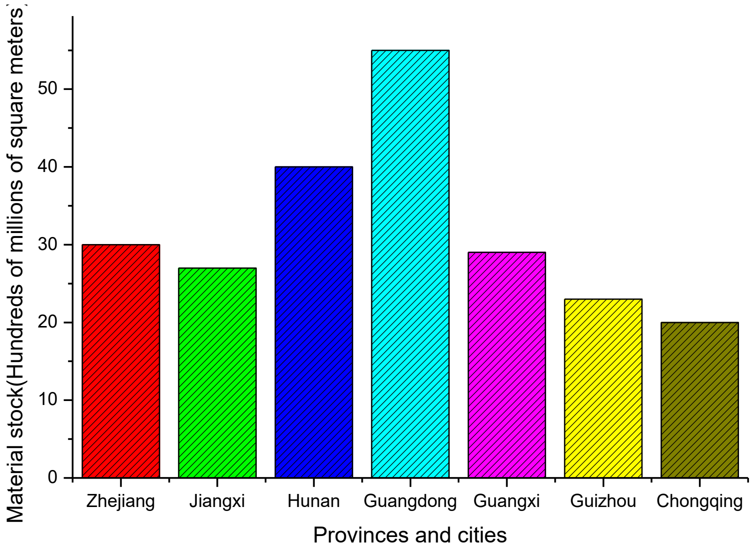

Figure 2: Material storage in acid rain area

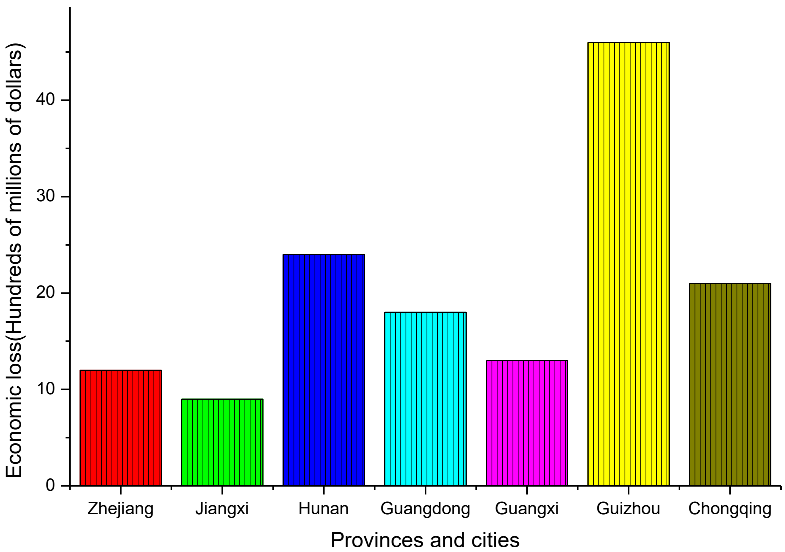

Figure 3: Economic loss of material damage in acid rain area

As shown in Table 3, the economic loss of materials due to acid rain is huge. Among them, in Guizhou and Chongqing, it has reached 4.13% and 1.19% of GDP YoY, respectively, which shows that the economic loss has already produced a great impact on the social economy.

As shown in Fig. 2 and Fig. 3, in the seven provinces and cities where there is acid rain, the Guangdong Province has a maximum stock of exposed materials, and Guizhou and Chongqing have the minimum. The economic losses in Guizhou and In Chongqing are the maximum, among the seven provinces and cities, the air quality in Guizhou and Chongqing is also the worst at a SO2 concentration and pH value of 0.067 mg/m3, 4.0 and 0.108 mg/m3, 4.0, respectively. The above results further bear out that the acid deposition will indeed cause a serious damage to the materials.

4. Conclusion

From the estimation results of acid rain area, it can be seen that acid deposition has a serious impact on the economy of material destruction. High GDP has a high relative quality of life, a large housing area and a large amount of exposed materials, so the provinces and cities with high GDP will suffer great economic losses from acid deposition. In addition, the volume of the car, the number of cars and provinces and cities are also greatly affected. According to the results estimated in this paper, the economic losses caused by atmospheric acid deposition to material damage are heavy, indicating that acid deposition to material damage is very serious. With the development of industry, air pollution is becoming more and more serious, and economic losses will be more and more serious. So how to effectively control acid deposition will be the key to the problem.

Reference

Ana M., Petrović S.S., Dragićević B.P., Radić, Ana, Z., Milanović P., 2015, Historical torrential flood events in the kolubara river basin, Natural Hazards, 79(1), 537-547.

Balasubramanian R., Ayyasamy E., Shanmugam S., Kumar A., Tammana J., 2016, Experimental investigation of the effect of different cooling methods on drill- induced damage in pultruded composites, Polymer Composites, 37(9), 2855-2859.

Choi J., Cho Y., 2016, Feasibility Study on Diagnosis of Material Damage Using Bulk Wave Mixing Technique, Journal of the Korean Society for Nondestructive Testing, 36(1), 53-59, DOI: 10.7779/JKSNT.2016.36.1.53.

Garrelts H., Lange H., 2011, Path dependencies and path change in complex fields of action: climate adaptation policies in germany in the realm of flood risk management, Ambio, 40(2), 200-209.

Jusoh N., Noah N.F.M., Othman N., 2018, Double Emulsion (Water-in-Oil-in-Water) System in Succinic Acid Extraction - A Stability Study, Chemical Engineering Transactions, 63, 523-528, DOI: 10.3303/CET1863088

Lee S.W., Yang W.J., Yi W.H., 2014, A Study on the Estimation of Economic Loss Costs due to Seismic Damage of Low Rise Steel Structures, Applied Mechanics & Materials, 470, 1011-1014. DOI: 10.4028/www.scientific.net/AMM.470.1011.

Meroni F., Squarcina T., Pessina V., 2017, A Damage Scenario for the 2012 Northern Italy Earthquakes and Estimation of the Economic Losses to Residential Buildings, International Journal of Disaster Risk Science, 8 (3), 326-341. DOI: 10.1007/s13753-017-0142-9.

Nour F., Nasri M., Yeganeh H., 2013, Estimation of economic losses of soil erosion of rangelands using nutrient replacement cost method (NRCM, Iranian Journal of Range & Desert Research, 39 (4), 22-530. DOI: 10.1016/j.ceramint.2012.11.039.

Shao Z., Tiong R. L. K., 2015, Estimating potential economic loss from damage to rc buildings in singapore due to far-field seismic risk, Journal of Earthquake Engineering, 19(5), 770-783.

Tatano H., Tsuchiya S., 2008, A framework for economic loss estimation due to seismic transportation network disruption: a spatial computable general equilibrium approach, Natural Hazards, 44(2), 253-265.

Tezuka S., Takiguchi H., Kazama S., Sato A., Kawagoe S., Sarukkalige R., 2014, Estimation of the effects of climate change on flood-triggered economic losses in japan, International Journal of Disaster Risk Reduction, 9(1), 58-67.

Zhang Y., Li Q., Zhang F., 2017, Estimates of Economic Loss of Materials Caused by Acid Deposition in China, Sustainability, 9 (4), 488. DOI: 10.3390/su9040488.

Zhuang W., Xie D., Chen Y., 2016, Experimental investigation of the effect of the material damage induced in sheet metal forming process on the service performance of 22mnb5 steel, Chinese Journal of Mechanical Engineering, 29(4), 1-9.