The Present State of Acidic Deposition and Its Countermeasures in China
中国における酸性降下物の現状とその対策

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Abstract：Acidic deposition has become a major worldwide environmental problem, and the effects of acidic deposition has been noticeable through dying forests, increasing acidity of lakes and reservoirs, and the destruction of outdoor sculptures and buildings. And it often touches off problems beyond the borders due to that the acidic pollutants may fall several thousand kilometers away from the emission sources. It is necessary to establish what the current situation is in these areas. The objective of this paper is to describe the present state and trends of acidic deposition and its countermeasures in China. The nationwide research projects, major research fields involved, the control policy and mitigate measures are also discussed in this paper.

The results show that the acidic deposition mainly distributed in the south of Yangtze (Chang Jiang) River, few acidic depositions were recorded in northern and eastern China. Local pollution is the major reason responsible for acidic deposition, while long range transport plays a relatively minor role. The area affected by acidic deposition accounts for about 6.8 % of the total area of the state, and the area with serious problems accounts for 11.7 % of the total area affected by acidic deposition. The problem of acidic deposition shows a tendency that it is more serious in southern area than in northern area. pH of precipitation in fall and winter is usually lower than that in spring and summer. $SO_4^=$ represents the major reason for the acidic deposition in China. A significant relationship exists between pH and atmospheric concentration of $SO_4^=$ and concentration of particle material.

Keywords：Acidic deposition, China, Sulfur oxides, Nitrogen oxides, pH

1. Introduction

Acidic pollutants fall on the surface of the earth in the form of acid rain and cause diverse effects. Acid rain often touches off problems beyond the borders because it sometimes falls several thousand kilometers away from the emission sources. Actually, acidic deposition began to attract attention as a regional scale environmental problem during 1970s in the northeastern part of the United States, southeastern Canada, southwestern Scotland, and parts of the Scandinavian countries. Damage caused by acid rain to soil, forests, lakes, and buildings have been reported.

Acid rain has the most direct impact on lakes, reservoirs and rivers. A number of lakes have been acidified in the northeastern part of the United States, southeastern Canada, southwestern Scotland, and parts of the Scandinavian countries. Damage on aquatic life is in evidence in 2500 Swedish lakes which have been affected by acid rain believed attributable

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to sulfur oxides and nitrogen oxides mainly from the central industrial belt in Europe. Damage is expected in 6500 other lakes in that country (Sudo and Xu, 1993).

Damage caused by acid rain to soil, forests and buildings in Sweden have also been reported. As for effects on human health, there is concern over the possibility that metals dissolved from bronze pipes resulting from the acidification of the sources of drinking water or those dissolved into the environment by the acidification of soil may find their way into the body through the food chain.

More recently attention has been paid to acidic deposition in northeastern Asia. Especially, in China, about 18 million tons sulfur oxides and 7.5 million tons nitrogen compounds are expected to be released annually to the atmosphere, because coal is used as a predominant source of energy. Main part of such an enormous amount of pollutants deposits within its own territories. However, their possibility to be carried over to Korea and Japan is quite high, especially in winter season. The demand of the energy and the development of the industrial activities in China are expected to grow more and more rapidly in the near future. However, studies on the regional environment in China have just started. SO_2 in many developing countries has been almost released from the coal combustors without SO_2 abatement process. Therefore, serious effects of acidic precipitation have been recognized in China, particularly in the new southwestern industrial regions now exploiting extensive nearly coal deposits of high sulfur content. To evaluate the effects of the acidic deposition on the terrestrial and aquatic ecosystems, it is important to accumulate the fundamental data on precipitation chemistry such as SO_2, NO_x, TSP, cation and anion component in these areas (Wang et al., 1993,1993a).

Considerable research has been performed and hundreds of scientific papers and several major books and reports have been written on the subject. We now have a good understanding of the nature and extent of at least wet acidic deposition, and we know that current low pH values for wet fall are caused primarily by sulfur and nitrogen oxide emission from combustion of fossil fuels. The most important contributions are the assessment of the significance of these variations to our understanding of the acidic deposition phenomenon and its implications for public policy decisions (Charles, 1991).

In order to resolve the mechanisms of formation of acidic deposition and define effective countermeasures for the future, it is necessary to establish what the current situation is in these areas. The objective of this report is to describe the present state and trends of acidic deposition and its countermeasures in China. The nationwide research projects, major research fields involved, the control policy and mitigate measures are also discussed in this paper.

2. A brief history of nationwide study on acidic deposition

Study on the acidic deposition in China initiated in Sichun province (located in the southwestern China), and the monitoring was occasional carried out before 1982. After 1982 , the Environmental Protection Agency (EPA) of the State Council issued a national monitoring project with the purpose of getting an outline of the acidic deposition in whole China(Zhao, 1988).

Formal nationwide project on acidic deposition started in 1985 and titled with "Source of Acidic Deposition in China and the Policy of Control". This was supported by the State Planning Committee and was chaired by Chinese EPA. The detail projects included five sub-projects which were shown in Table 1.

Results of the projects showed that acidic deposition mainly appeared in some areas of southwest and southern China. In some region the problem is even more serious and economic loss was record. This arose deep concern of the state government and an investment of 5.5 million Yuan (RMB) was afforded to continue the study, especially in southwestern

and southern China. This directly led to a project titled with study on the Acid Rain, one of the key projects of state's seventy-five-year plan (from 1985-1990). The project composed of two sub-projects including Study on the Acid Rain in Southwestern China and Study on the Acid Rain in Southern China. Both included five topics as listed below (Wang, 1993, 1993a, 1993b; Xu et al., 1994).

Table 1 Key Projects of State's Seventy-five-year Plan

Topics No.	Contents
1	Acidic Deposition at the State Level
2	Acidic Deposition in Southwestern China and Its Ecological Effect
3	Acidic Deposition in Southern China
4	Acidic Deposition in Ermei Mountain Area Its Source and Transport
5	Ecological Effect Attributed to Acidic Deposition.

1) The present status of acid rain in the project area;
2) The Transport of acidic pollutants;
3) The chemical procedure of acidic deposition;
4) The ecological effect of acidic deposition
5) The controlling policy of acidic deposition

With the completion of these two projects, China primarily got the results of distribution, monthly and annual dynamic and trend of its acidic deposition in the scale of whole nation. Meanwhile, in some areas with serious problems of acidic deposition, the study on source of acidic pollutants, transport and ecological effect were also emphasized. The same survey in the central and eastern China was also carried out. In 1990-1995 project an inter-discipline and inter-ministry research network is established.

3. Major research fields

Beside the nationwide research projects, many topics are also under study. Three major fields are included:

1) Distribution, dynamic and trends of acidic deposition;

In this field, studies include geological and vertical distribution dynamic and trend of variation of pH and related chemical components, atmospheric background of precipitation, the relationship between acidity and other chemical, physical, geological and meteorological factors, and relationship between acidic deposition and air pollutants. Monitoring plays an indispensable role in the studies of acidic deposition. After 1982, more than 300 monitoring stations and about 900 field points were established in 26 provinces and autonomous regions all over the country except Xinjiang, Tibet and Taiwan. Fig.1 shows the distribution of monitoring stations of acid rain in China.

In 1986, after several years of research, the "State Standard Methods for Monitoring and Analysis of Chemical Components in Precipitation" was published. It set up rules concerning field points disposition, sample collection and transport, monitoring and analytical instruments, and standard methods for laboratory analysis. Quality control and assurance system was established and regular assessment on the work of monitoring stations was conducted.

2) Physical and chemical procedure;

Research topics in this field cover influence factors of precipitation's acidity; Formation of acidic deposition; Relationship between acidic deposition and meteorological system; and source of acidic pollutants, its transport and statistic modelling.

3) Ecological effect and economic loss

Ecological effect attributed to acidic deposition can be found on terrestrials and aquatic ecosystem and constructing material. Studies in this field include: (1) modelling experiment of acidic deposition on plants; (2) analysis on the relationship between acidic deposition and forestry damage; (3) effect of acidic deposition on plankton and fish community; (4) sensitivity of soil to acidic deposition; (5) mechanism of erosion of acidic deposition on constructing material. As several nationwide projects on acidic deposition disclosed the serious effect on the environment. This research field comes to be more and more important in the study of acidic deposition.

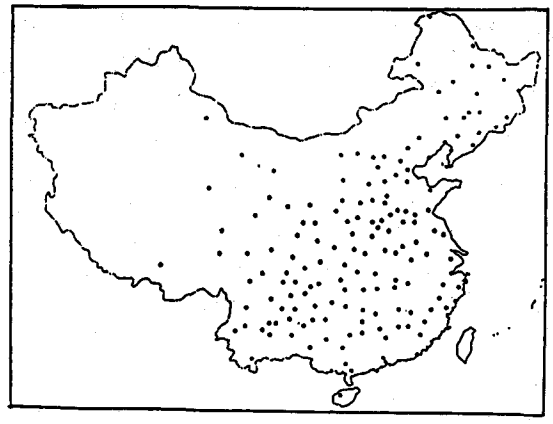

Fig.1 Distribution of the Monitoring Stations of Acid Rain in China(1992)

4. The present status of acidic deposition in China

Results of several nationwide project identified the status of acidic deposition in China. The results show that the acidic deposition mainly distributed to the south of Yangtze River, especially in four regions including (1) Sichuan Basin; (2) Guizhou Province; (3) Hunan, Hubei, and Jianxi provinces; (4) Coastal provinces area of Fujian, Guangdong . Few acidic deposition is recorded in northern and eastern China. Local pollution is the major reason responsible for acidic deposition while long range transport plays a relatively minor role. The area affected by acidic deposition accounts for about 6.8 % of the total area of the state and area with serious problem account for 11.7 % of the total area affected by acidic deposition. Fig.2 shows the distribution of the acidic deposition in China in 1990.

The problem of acidic deposition shows a tendency that is more serious in southern areas than in northern areas. This is because the pH values of soil in northern China ranged from 7-8, while the pH values of soil in southern China ranged from 5-6. Fig.3 shows the distribution of the pH values of soil in China. And the chemical components of precipitation are much different between southern and northern areas (Table 2). The components of NH_4^+ and alkali metal were higher in northern area than that in the south.

The trends of total suspended particles (TSP) concentrations in cities have decreased

Table 2 The main Chemical components of precipitation in northern and southern cities

	stations	Samplers	$SO_4^=$	NO_3^-	NH_4^+	Ca^{2+}	Mg^{2+}	$SO_4^=/NO_3^-$	pH
	Beijing	28	154.5	39.5	162.8	151.6	12.1	3.91	6.90
	Changchun	34	156.5	21.2	61.3	256.5	51.2	7.38	6.71
North	Shenyang	19	398.0	50.3	99.0	305.4	395.3	7.96	6.41
	Xian	5	358.1	67.3	275.8	1795.4	66.84	5.32	7.15
	Yantai	2	182.5	22.8	39.1	289.1	20.1	8.00	6.97
	Chongqing	21	326.6	27.9	151.1	127.8	31.5	11.7	4.21
	Guiyang	4	405.2	27.9	174.3	199.6	65.2	14.5	4.23
South	Nanning	29	61.6	4.9	27.7	26.6	1.4	12.6	4.82
	Shanghai	36	153.4	12.6	75.8	104.3	27.9	12.2	4.85
	Hefei	42	141.9	31.8	117.3	110.3	13.7	4.46	4.73

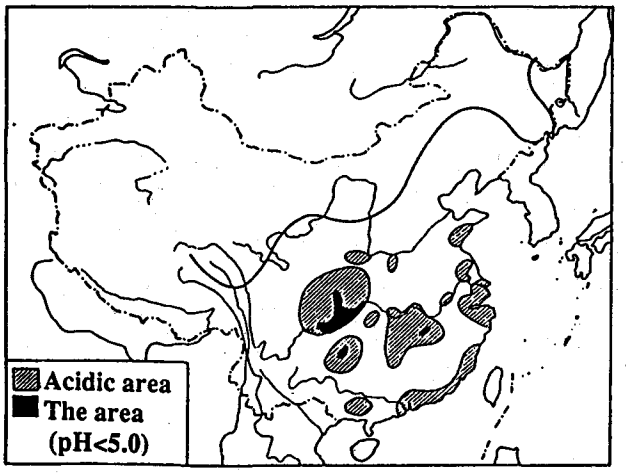

Fig.2 Distribution of the Acidic Deposition in China(1985-1990)

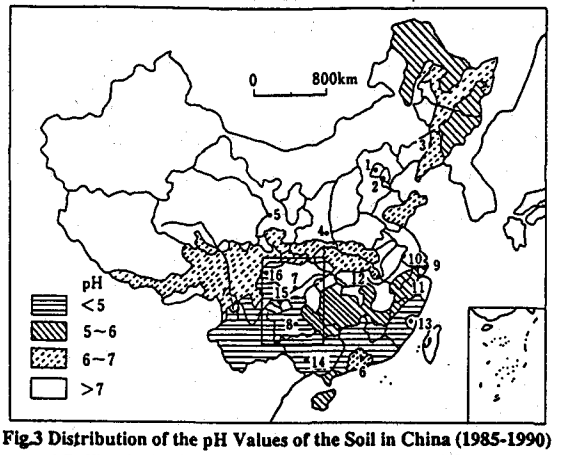

Fig.3 Distribution of the pH Values of the Soil in China (1985-1990)
1.Beijing 2.Tianjin 3.Shenyang 4.Xian 5.Lanzhou 6.Guanzhou 7.Chongqing 8.Guiuyang 9.Shanghai 10.Nanjing 11.Hangzhou 12.Wuhan 13.Fuzhou 14.Nanning 15.Yibing 16.Chengdu

greatly either in southern or northern cities in the past decade due to effective control of smoke dust for coal burning. For example, TSP annual average concentration from 700μg/m^3 in 1981 dropped to 400 μg/m^3 in 1990. Southern cities have TSP annual average concentrations lower than national standards, but in northern cities it is still higher than the standards. The trends of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) concentrations in cities have not changed apparently (Wang et.al.,1993). The distributions of the pH value of China in 1992 and 1982 were shown in Fig.4. It can be seen from the graph that the distribution of low pH area has been enlarged form 1982 to 1992. The acidic area is located at southeastern China (Wang et al., 1993; Zhao, 1988).

The dominant fuel used in China is coal. Sulfur dioxide (SO_2) is the major pollutant responsible for acidic deposition. Fig.5 shows the emission intensities for SO_2 in China in 1990.

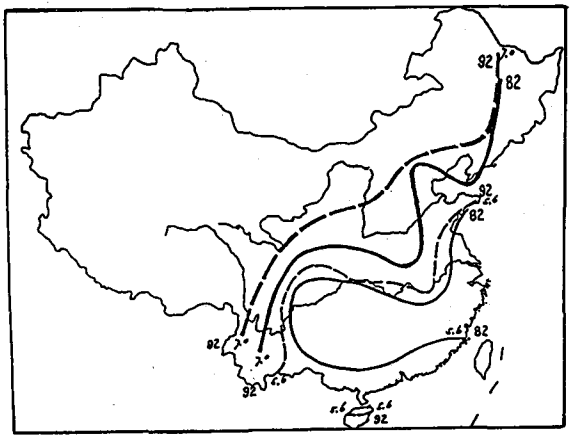

Fig.4 Distribution of pH Values of the Precipitation in 1982 and 1992

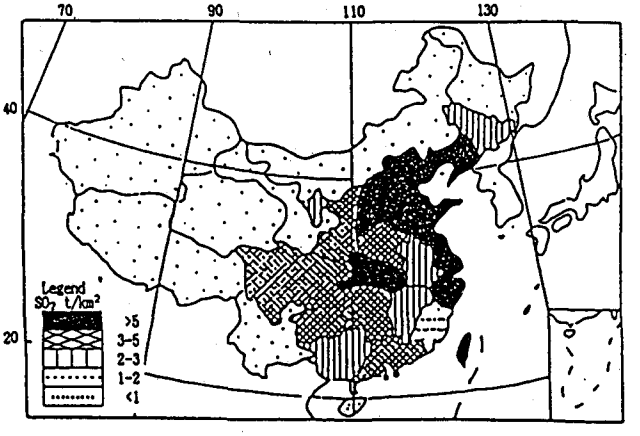

Fig.5 Regional-based Emission Strength of SO_2 in China (1990)

5. Control policy and countermeasure

The Chinese government take the environmental protection and pollution control as a basic national policy, and strive after solution of environmental protection while fostering the development of the economy and society. To promote the air pollution control, the government takes comprehensive measures of legislation, administration, social public opinion and economics.

In the respect of pollution control investment, it is increased to 16.6 billion yuan (RMB) from 1981 to 1985, accounts for 0.5% of GNP and 47.7 billion yuan from 1986 to 1990, makes up 0.7% of GNP. The annual investments were listed in Table 3. It can be seen that the annual investment increased four fold from 1981 to 1990, and a further increase of

percentage will be going to take place steadily.

Annual investment for air pollution treatment was listed in Table 4. It can be seen that the investment for air pollution treatment was doubled from 1985 to 1990. As a result, the smoke dust emissions from coal burning were to be controlled under 14 million tons, and the industrial dust emissions were cut down to 40%.

However, we must pay attention to the air pollution that is controlled on the basis of high pollution level. It will take a considerably long period, Tremendous efforts and large funds to thoroughly improve the urban air quality other than that the new techniques in air pollution control should be developed.

The extent of the problem varies in different cities. Of the cities listed above, northern cities appear to have the most severe problem with respect to TSP while the southern cities have higher SO_2 levels.

Table 3 The Environmental Protection Investment Over The Years And Its Rate In GNP In China

Year	Environmental protection investment (billion yuan)	GNP (billion yuan)	Environmental protection investment rate in GNP (%)
1981	2.500	477.3	0.52
1982	2.866	519.3	0.55
1983	3.072	580.9	0.53
1984	3.336	696.2	0.48
1985	4.850	855.8	0.47
1986	7.389	969.6	0.76
1987	9.189	1130.1	0.81
1988	9.998	1398.4	0.72
1989	10.249	1578.9	0.65
1990	10.906	1740.0	0.63

Sources: China Statistics Yearbook, China Urban Construction Yearbook, Annual Report on Environmental Statistics.

Table 4 The Waste Gas Treatment State In China (1985-1990)

Item	Unit	1985	1986	1987	1988	1989	1990
Waste gas treatment funds	billion yuan	0.728	0.959	1.242	1.528	1.577	1.480
Total emissions	billion m^3	7397.0	6967.9	7727.5	8238.0	8306.5	8542.2
SO_2 emissions	million tons	13.25	12.50	14.12	15.23	15.56	14.95
Smoke dust emissions	million tons	12.95	13.84	14.45	14.86	13.98	13.24
Industrial dust emissions	million tons	13.05	10.75	10.04	11.25	8.40	7.81
New added tratment capacity	billion m^3	617.7	370.4	319.6	434.3	473.4	442.1

Source: Annual Report on Environmental Statistics.

It was mentioned earlier in this paper that the major reason for the higher levels of particulate and SO_2 in Chinese cities is the direct combustion of coal in small and inefficient boilers.

All of the coal-fired power plants and large industries have installed electrostatic precipitator to reduce emissions of particulate but almost without desulfurization equipment because which is very expensive.

At present, to switch to cleaner energy sources, such as natural gas and liquefied petroleum gas, to centralize heating supply as well as coal gasification in cities have been spreading rapidly.

In this respect, some techniques for boiler including industrial and power plant boilers have been developing as follows, industrial briquette, high efficiency precipitator, coal combustion sulphur retention bubbling boilers, phosphate ammonium fertilizer process in FGD (Flue Gas Desulfurization), rotating spray in FGD process and active carbon catalyst to produce sulfuric acid in FGD etc. But the desulfurization plants are very expensive, the desulfurization installation in large scale might not be equipped in the near future.

As mentioned above, the dominant fuel used in China is coal. SO_2 is the major pollutant responsible for acidic deposition. The removal of sulfur from coal prior to combustion is an attractive emission control strategy. So to control acidic deposition is to control the atmospheric

concentration of SO_2 and to reduce the emission of SO_2, a series of policies and countermeasures are taken to complete the target:

(1) Rationalizing the distribution of industries

a) Implementing regulation on environment evaluation before construction of any new industry.

b) Improving old industries of unreasonable distribution

(2) Saving energy, reducing pollutants emission

(3) Revising the fuel structure of domestic usage

(4) Improving technique of combustion

(5) Strengthening regulation on the discharge of gaseous pollutants from automobile

(6) Strengthening environmental legislation

(7) Supporting studies on control technology

(8) Developing energy with low pollution or without pollution

6. Conclusions

Results of several nationwide project identified the status of acidic deposition in China. The results show that the acidic deposition mainly distributed to the south of Yangtze River, especially in four regions including (1) Sichuan Basin; (2) Guizhou Province; (3) Hunan, Hubei, and Jianxi provinces; (4) Coastal provinces areas of Fujian, Guangdong . Few acidic deposition is recorded in northern and eastern China. Local pollution is the major reason responsible for acidic deposition while long range transport plays a relatively minor role. The area affected by acidic deposition accounts for about 6.8 % of the total area of the state and area with serious problem account for 11.7 % of the total area affected by acidic deposition.

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References

Charles Donald F. : Acidic Deposition and Aquatic Ecosystems, Springer-Verlag New York Inc. 9-34, 1991.

National Environmental Protection Agency, China Environment Yearbook (in Chinese), China Environmental Science Press, Beijing, 1992

National Environmental Protection Agency, 20 Years of Environmental Monitoring in China (in Chinese), 1993

State Statistic Bureau of China: China Statistic Yearbook (in Chinese), China Statistics Publishing House, Beijing, 1991.

Sudo Ryuichi and Xu Kai-Qin : Effects of acid deposition on water environment (in

Japanese), Journal of Resources and Environment, Vol.29, No.2, p.119-130. 1993

Wang Wenxing et al.: Study on Air Pollution and Its Control in China, The Proceedings of the 34th Annual Meeting of the Japan Society of Air Pollution, Chiba, p.7-12, 1993

Wang Wenxing et al.: Study on the Factors of Acid Rain Formation in China, China Environmental Science Vol.14, No.6, 1993a

Wang Yuqing.: The Status of Environmental Pollution and Countermeasures in China, China Environmental Science Vol.4, p.1-8, 1993b

Xu Kai-Qin, Wang Wenxing and Sudo Ryuichi : Air pollution and its control in China, MAB Researches related to the UNESCO's Man and the Biosphere Programma in Japan, p.81-88, 1994

Zhao D. : Acid rain in southwestern China, Atmospheric Environment, 22, 349-358, 1988