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Current Situation and Possible Solutions of Acid Rain in South Korea

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***Abstract*—**Environmental statistics reveals that the pollution of acid rain in South Korea is a serious issue. Yet the awareness of people is low. Even after a gradual decrease of pollutant emission in Korea, the acidity has not been reduced. There no boundaries in the atmosphere are set and the influence of the neighboring countries such as China is apparent. Governmental efforts among China, Japan and Korea have been made on this issue. However, not much progress has been observed. Along with the governmental activities, therefore, an active monitoring of the pollution among the countries and the promotion of environmental awareness at the civil level including especially the middle and high schools are highly recommended. It will be this young generation who will face damaged country as inheritance not the current generation.

***Keywords*—**acid rain, international collaboration, pollution, South Korea

I. Introduction

TERMINOLOGY, acid rain, was first introduced by British chemist Angus Smith in 1852. He reported that ammonium carbonate [$(NH_4)_2CO_3$] was in the air over farming area, ammonium sulfate in the suburbs and sulfuric acid in the city. They dissolved in rain and rain became to be strong acidic. An interest on acid rain increased sharply by a German report that acid rain was responsible for the devastation of forest. Further studies had been followed by various researchers and the pollution due to industrialization and massive emission of NO_2 from the automobiles were known to be a cause of producing strong acid rain. Rain whose acidity is lower than pH 5.6 is defined as acid rain. Non-polluted water has a pH of 7.0 and becomes acidic when mixed with pollutants. The study of acid rain can be classified into two different approaches. The first approach is to study chemical reactions in the atmosphere or to examine the damage due to acid rain [1-3]. The other one is to find out methods or policies that can reduce acid rain through socio-scientific studies [4]. However, the proposed policies should be based on the understanding of chemical phenomenon. Both approaches should be considered in order to study an acid rain problem. And this is what we want to do.

In this study, we examine the researches on the origin of acid rain and find that acid rain is produced not only by pollutants in the local region but by those travelled from other regions including other countries through the atmospheric flow. The pollutants from other jurisdictions, for example other nation, can be more difficult to deal with since it is not easy to act against them.

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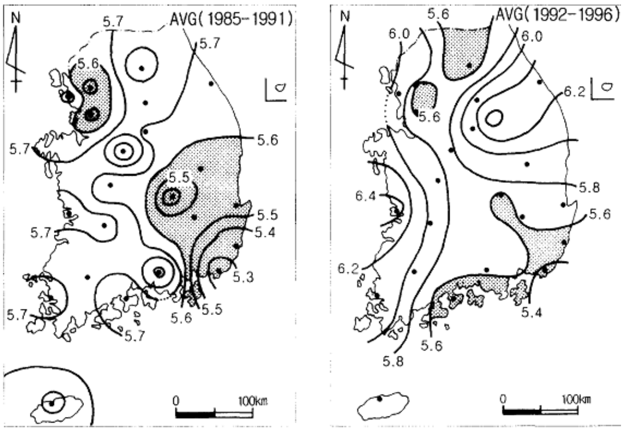
Therefore all the geographical regions responsible for pollution should participate and possible solutions should be studied jointly. We examined the characteristics of acid rain occurrence in South Korea and examined its causes. In addition, we investigated what kinds of efforts have been made to reduce or minimize acid rain and what have been the progresses. Lastly, we discussed what kinds of effective policies can be suggested for acid rain.

II. Occurrence and Distributions of Acid Rain in South Korea

Acid rain has become a worldwide issue as environmental problem since 1980's. From the latter part of 1980's, nations regulated the emission of sulfur oxides and nitrogen oxides. Actually the release of sulfur oxides and nitrogen oxides has been reduced substantially since 1990's and it appeared that the problem of acid rain was almost solved. The discharge of sulfur oxides was reduced. Nevertheless, the acidity of rain was not weakened. The reason was the reduction of alkaline materials simultaneously that neutralized the acidity of rain [3]. Alkaline dust and suspended solids were reduced as road pavement expanded. Alkaline dust became less in the air also through the efforts of reducing dust discharges that were produced from the factories and power plants. As a result, acid rain appears still strong in 2011 in South Korea. Rather, public attention decreased than before. It seems that acid rain is not a top priority any more due to other environmental issues.

According to the geographical distributions of acid rain in 1980's, there were more acid rain in Seoul and Pusan which are the largest cities. This is shown in Fig. 1. Fig. 1 shows pH values of rain in South Korea and compares the geographical distributions of pH values in the periods between 1985 and 1991 and between 1992 and 1996. Other regions of more acid rain were Yeocheon area in Jeolla-do, the south-east Imhae Industrial Region comprising Ulsan and Changwon. In 1990's, the metropolitan area and west coast regions had reduced acidity in rain and acid rain in the south region decreased as well. Imhae Industrial Region that covers Changwon and Kwangyang appeared as an area of acid rain. Mentioned as in the above, the geographical distribution of Korean acid rain consisted of large cities and industrial areas.

Table I shows yearly acidity in precipitation for major cities between 1992 and 2008. Acidity did not decrease at all and remained as strong. Rain acidity in Seoul had a 14-year average of pH 5.0 in the period of 1992 and 2006. Other cities like Pusan had a strong acidity in pH 5's.



Fig, 1 pH distributions over major cities in South Korea from Reference [1]. Values given are the yearly average. Left figure was between 1985 and 1991 and Right figure between 1992 and 1996

TABLE I
PH VALUES IN YEARLY PRECIPITATION FOR MAJOR CITIES

	Seoul	Pusan	Daegu	Incheon	Kwang -ju	Daejeon	average
1992	5.3	5.2	5.6	6.2	5.7	5.7	5.6
1993	5.4	5.3	5.5	5.8	5.8	5.8	5.6
1994	5.4	5.3	5.6	6	5.8	5.8	5.7
1995	5.8	5.2	5.7	5.9	6.2	6.2	5.8
1996	5.7	5.2	5.6	5.9	5.9	5.9	5.7
1997	5.3	5.2	5.8	5	5.9	5.9	5.5
1998	4.9	4.7	5.4	4.4	4.8	4.8	4.8
1999	5	4.8	5.6	4.6	5.2	5.2	5.1
2000	4.8	4.9	5.8	5	5.2	5.2	5.2
2001	4.7	5	6	4.7	5	5	5.1
2002	5	6.2	5.6	4.8	5.1	5.1	5.3
2003	4.8	4.9	4.8	4.7	5	5	4.9
2004	4.5	5	5.3	4.7	5.2	5.2	5.0
2005	4.4	4.8	5.3	4.5	4.8	4.8	4.8
2006	4.7	5.7	5.5	5.4	5.2	5.2	5.3
2007*	4.8	5.5	5.6	4.8	4.7	4.7	5.0
2008*	4.8	5.1	5.5	4.8	4.5	4.5	4.9
average	5.0	5.2	5.5	5.1	5.3	5.3	

A white paper on environment, Ministry of Environment, South Korea, pp 399, 2007. The 2009 Yearbook of Environmental Statistics, pp 232

According to yearly changes in acidity, it is not straightforward to select a certain characteristics even though the year 1995 had the strongest acidity and a gradual decrease was shown since then. National Environmental Research Institute measured pH and the wet deposition amount in rain at 31 locations throughout the country. The average pH between 1999 and 2003 was 4.7 ~ 5.1 [2] and the numbers were similar to those given in Table I. Acid rain appeared in all the regions of the south Korean Peninsula and acidity remained stronger.

Table II shows pH throughout the world. If we look into other countries, we find that Taipei in Taiwan, China, Singapore and Malaysia had low pH values. Taipei was 4.37 and Malaysia was 4.3. Neighboring countries were not exceptions. In case of Japan in 1990~1999, pH was as low as 4.56. Even though data were from 1980's or 1990's, we see that acid rain should be a worldwide issue.

TABLE II
THE PH, SUMS OF ANION AND CATION CONCENTRATIONS OF PRECIPITATION AND ACID RAIN GRADE OF THE WORLD [2]

location	period	No of sites	pH	Total anion	Total cation
Tanah Rata (Malaysia)	1990~1992	1	5.13	16.2	22.8
New South Wale (Australia)	1992~1994	4	4.82	19.0	35.2
Rural area (India)	-	-	5.63	41.6	47.9
Bhubaneswar (India)	-	-	-	44.4	55.2
Malaysia (Whole)	1996	5	4.30	54.1	85.3
California (USA)	1972~1973	2	5.10	57.2	60.6
Emei Mt. (China)	1982~1986	1	4.54	58.0	122.0
Florida (USA)	1978~1987	1	4.59	64.9	79.1
Whiteface Mt. (USA)	1986~1989	1	-	66.4	74.0
Narayangani (Bangladesh)	1994~1995	4	6.35	71.5	111.7
Sogndal (Norway)	1984~1987	2	4.80	71.6	82.0
Sonbhadra (India)	1999	1	6.95	80.9	129.5
Haliburton-Muskoka(Canada)	1976~1978	8	-	83.4	166.8
Pune (India)	1992~1994	-	6.28	84.7	154.2
N.E. Vietnam	1997~2000	5	5.80	87.8	77.8
Hubbard Brook, NY (USA)	1963~1974	1	4.14	97.3	102.9
Singapore	1997~1998	1	4.50	97.6	127.5
Korea (Whole)	2000~2003	31	4.90	101.3	124.0
Pallanza (Italy)	1984~1986	1	4.40	120.0	129.0
Japan (Whole)	1989~1993	29	4.80	122.0	117.4
New England (USA)	1978	1	4.06	128.0	129.0
Tokyo (Japan)	1990~1999	9	4.56	131.2	147.3
Rural 4 areas (Japan)	1996~1999	4	-	147.2	152.8
Guongyang (China)	1982~1986	1	-	186.0	399.4
Gwangneung (Korea)	1991~1993	1	5.65	199.2	93.8
Guangzhou (China)	1998~1999	2	4.39	241.3	261.4
Taipai (Taiwan)	1991~1995	1	4.37	269.8	275.7
Kwanaksan (Korea)	1992~1993	1	-	341.5	587.9
Neijang (China)	1982~1986	1	-	344.0	625.0
Guiyang (China)	1982~1986	1	-	379.0	422.0
Amman (Jordan)	1996~1997	2	6.20	424.6	578.8
Beijing (China)	1995~1998	2	6.76	503.8	672.4
Chongquing (China)	1987~1989	1,351	4.29	541.7	704.1

Now we will investigate how much substances responsible for acid rain were emitted and examine the relation between the acidity in precipitation and the release of pollutants. Typical substances known for producing acid rain are sulfur dioxide and nitrogen oxide. Sulfur dioxide is mainly emitted from power plant or produced during the combustion of fossil fuel. Sulfur dioxide is floating in the atmosphere. It interacts with oxygen and water vapor and produces sulfuric acid. Sulfuric acid in the atmosphere becomes sulfur trioxide by oxidation process. Sulfur trioxide is dissolved into water drop and rain becomes more acidic. Nitrogen oxide is also naturally produced during lightening discharge in the atmosphere.

It is mainly produced during combustion process of fuels such as coal and petroleum. Nitrogen oxide interacts with water vapors in the air and nitric acid is produced. Gas emission of automobiles or high-temperature emission gas from the incinerator is responsible for producing nitrogen oxide when nitrogen and oxygen are interacted.

The emission of nitrogen oxide increases as the number of automobiles increases. Fig. 2 shows the emission of sulfur dioxide and nitrogen oxide between 1991 and 2009.

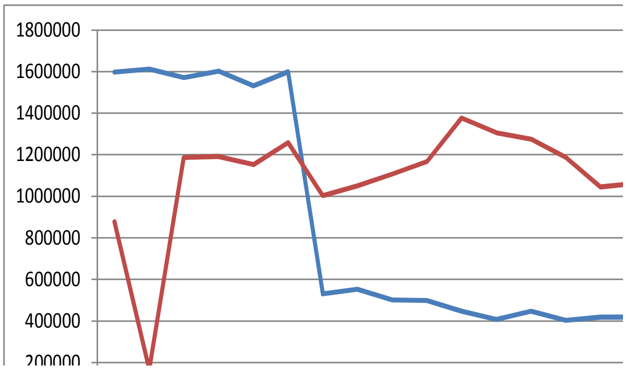


Fig. 2 Emission of sulfur oxide (SO_2) and nitrogen oxide (NO_X) [ton/year] in South Korea. Data between 1992 and 1996 were from Ref [1] and other data were from the Yearbook of Environmental Statistics, South Korea (2006 and 2009)

As shown in Fig. 2, the emission of SO_2 was reduced sharply in 2000's only to one-third of 1990's. To the contrary, NO_X had a sharp increase in 1993 and remained strong since then. We may say that there was a gradual decrease after 2004. Fig. 2 indicates that pollutants decreased. In spite of the decrease of pollutants, interestingly enough we see that the acidity in rain did not decrease.

In order to analyze this phenomenon, we studied the characteristics of acid rain in South Korea. We find that rain had a tendency of weak acidity from February and April. As shown in Fig. 3, rain became more acidic entering the autumn. We speculate that values of pH became smaller in summer since there was more rain in summer and that rain diluted the proportions of sulfur oxide and nitrogen oxide. Monthly precipitation in Seoul is given in Fig. 4.

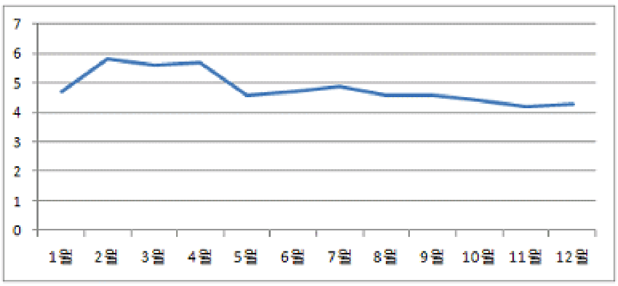


Fig. 3 Monthly pH values of rain in Seoul in2008. Data were from the Yearbook of Environmental Statistics, South Korea (2009).

The acidity in spring becomes weak. This phenomenon appears to be not related with precipitation since there is less rain in spring. This may be explained by the fact that cations are abundant in rain due to yellow sand [5]. Yellow sand and soil dust can travel over a very long distance during drought.

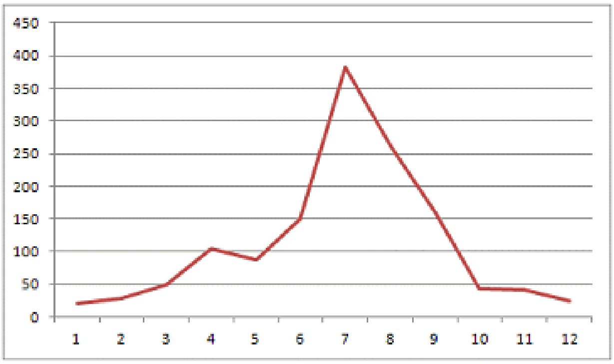


Fig. 4 Monthly precipitation in Seoul. http://www.kma.go.kr/weather/climate/average_regional.jsp (March 2, 2012)

TABLE III
PARTICULATE MATTER (PM_{10}) CONCENTRATIONS IN MAJOR CITIES IN 2009, SOUTH KOREA

month	Seoul		Pusan		Daegu		Incheon	
	ave	max	ave	max	ave	max	ave	max
Jan	57	143	44	116	49	117	57	161
Feb	81	240	63	157	64	178	78	227
Mar	60	276	50	247	50	246	64	273
Apr	66	177	62	141	54	127	76	195
May	57	116	57	159	49	121	62	149
June	50	131	54	154	46	116	55	136
July	41	88	42	114	38	86	46	104
Aug	31	92	37	102	31	95	39	113
Sep	39	94	39	83	37	87	52	148
Oct	51	155	55	145	51	128	62	204
Nov	46	153	39	119	45	161	53	153
Dec	71	359	52	180	62	211	76	437

Data were from the 2010 Yearbook of Environmental Statistics, South Korea

Table III shows particulate matter concentrations in major cities in South Korea. The average concentrations of the particulate matter were the highest in February. Usually February has very low precipitation as an example shown in Fig. 4. This supports an argument that the particulate matter of high concentration neutralized acid rain in this month of low precipitation.

Another interesting observation is that the acidity in rain was not determined only by the amount of emitted SO_2 and NO_X. A region with very little air pollution has acid rain. Jeju Island is a good example. Jeju Island is a famous resort and there are few air-polluting industries. In spite of this fact, acid rain was being observed in Jeju Island. Table IV shows pH's in rain at several locations in the island [3].

Ido-dong, Yeon-dong and Useungseang are located on the north slop area of Halla Mountain. Gosan-li is placed at the west tip of Jeju Island. Ido-dong and Yeon-dong are the central areas and have relatively large volumes of traffic. On the other hand, Useungseang is a forest area where there is no traffic. There are neither industries nor traffic that may produce pollution. Gosan-li is a typical farming area without substantial traffic and industries.

Interestingly, Useungseang and Gosan-li have acid rain as shown in Table IV. It suggests that acid rain in Jeju Island is not dependent only on pollutants generated at the local area.

TABLE IV
VALES OF pH IN ACID RAIN OF JEJU ISLAND [3]

	Ido-dong	Gosan-li	Yeon-dong	Useung-seang
1996	N/A	N/A	5.1	5.1
1997	N/A	N/A	5.4	5.3
1998	5.9	5.9	4.9	4.8
1999	5.6	5.4	5.2	5.2
2000	5.4	5.5	5.3	5.2
2001	4.8	4.4	5.2	5.1
2002	N/A	N/A	5.1	5

There are other places than Jeju Island in South Korea that were free from pollutions. We had a similar observation for those places. Anmyeondo in Yellow Sea and Uljin at the coast of East Sea showed very high acidity in rain [6]. In Table V, rain in Anmyeondo had an average of pH 4.8 and rain in Uljin had a pH of 4.87. These two places are free from industrial complex. There is little traffic in Anmyeondo which is an island. Very strong acid rain seen in pollution-free areas supports the theory that acid rain is not generated only by pollutions produced at the local area.

TABLE V
pH OF PRECIPITATION IN ANMYEONDO AND ULJIN

	Anmyeon-do	Uljin		Anmyeon-do	Uljin
1997	4.76	N/A	2001	4.72	4.98
1998	5.00	5.08	2002	4.76	4.96
1999	5.04	4.86	2003	4.43	4.88
2000	4.56	4.96	2004	4.74	4.72

So far what we observed regarding the features of acid rain in South Korea indicated that two substances (SO_2 and NO_X), known to induce acid rain, are not necessarily inversely proportional to the rain acidity. Furthermore, the areas that have little possibilities of producing SO_2 and NO_X have strong acid rain. Even we decrease pollutants we still have acid rain because pollutants come from other regions through air flow. Especially since 1990's, China has gone through a rapid development of industrialization, which emits a lot of pollutants. As the atmospheric flow is from west to east, they reach the Korean peninsula. Anmyeondo and Uljin are located in the ocean or at the coast and easily hit by pollutants traveling from overseas. pH values of these two locations were about 4.8. 4.8 was a similar number observed in the surrounding countries of Japan and China.

III. POLICIES TO REDUCE ACID RAIN

As discussed in the previous section, the characteristics of acid rain in South Korea can be summarized into two. First, the acidity in rain was an important issue in 1980's and the public attention has been somewhat diminished in 1990's. Strong acid rain has been still monitored not only in major cities but also in the coastal area and in the clean zones such as Jeju Island. The acidity is quite strong showing pH values between 4.4 and 5.0. This acidity can cause damages on fish eggs of salmon or trout [7]. Therefore we should be concerned with this environmental issue. Secondly, our acid rain is not only due to pollutants that we produce in the country. Pollutants produced from the neighboring countries travel in the air flow and reach the Korean peninsula. The opposite is also true.

We suggest some policies to cope with acid rain. First, we should be more aware of acid rain as serious environmental problem. In order to promote public awareness, we propose the obligatory installation of acid rain meter at the public sites. They include schools (elementary, secondary and high school), government offices, the cross roads and apartment complex, etc. Frequently and periodically, the acid rain meter takes rain sample and measures pH. It is recommended that pH values along with warning statements of potential hazards.

Secondly, we should double an effort to reduce or minimize the emission of pollutants responsible for acid rain. Promoting the public transportation and use of hybrid cars will reduce air pollution caused by the combustion of fossil fuel. As many researches stated, it is necessary to develop further and to use alternative energy sources. The regulations and provision of incentives by the governmental organizations are encouraged.

Thirdly, we want to emphasize international collaborations. There can be two levels. One is the civilian program and the other is the official program. As civilian program, schools or organizations that have already on-going collaboration programs may initiate a joint project to share the importance of acid rain issue as environmental problem and to discuss about various aspects on acid rain. Above all, students even in the early stage of education system have interests in this issue and try to come up with more solid collaboration and potential solutions.

There have been governmental collaborations. In 1979, the UN European economy committee played a pivotal role in establishing international policies to cope with the damage of acid rain and made a contract on Convention on Long-range Trans-boundary Air Pollution (CLTAP). In 1994, 30 countries reached an agreement of Oslo Protocol on SO_X [8]. Through CLTAP, the European Monitoring Evaluation Program was established and monitored SO_X emission among the member countries. Oslo Protocol was the agreement that the member countries decided to abide by their cutback goals. The cutback goal of each country was set of one's own accord. This was a good example of the international collaboration through an agreement among the nations was made and carried out. They made a monitoring system, imposed the goal of reduction rates or set the goals of individual nations within a certain time frame.

South Korea is also aware of trans-boundary characteristic of the origin in acid rain and makes an effort of some agreements in the north-east region. The north-east region produces an increasing amount of air pollution substances as rapid economic developments has been made. There is a need of international research collaboration among the neighboring nations like China and Japan regarding pollutants of travelling long distance.

In September 1995, the first workshop on long-distance travelling air pollution materials was opened and the joint organizing committee meeting was held two times. In January 1999, Ministers of the Environment Ministry from three countries of South Korea, China and Japan agreed to cooperate on atmospheric pollutions (yellow dust and acid rain). Following the agreement, in August 1999, the specialists form three countries established a 3-phase 5-year research plan to study measurements of air pollutants and to develop a model of predicting air pollution. In August 2002, joint research results were presented during the 5th specialist meeting. They discussed and agreed on the 4th year research plan (Sept 2002 - Aug 2003) and published three annual reports jointly up to that point. However, these international collaborations dealt only with principles and could not produce substantial results.

In order to achieve more substantial results, a couple of obligatory actions should be followed. First, in monitoring each country, we propose a swapping of specialists. For example, Korean specialists monitor Japan's environment and Japanese specialists check Chinese environment and so forth. The specialists who take part in monitoring prepare a report and present the results in the joint environment Minister meeting. Based on these monitoring, each country is expected to set the goals of reducing the pollutants at the periods of 5, 10 and 15 years. Also we suggest that a protocol with these reduction goals written on it be signed at the summit meeting.

Lastly the adult generation is bound in political and economical system. They may not see the environmental issue as top priority. After all it will be the young generation, not the current generation, who will live in an environmentally devastated world if we do not act now accordingly now. That is why the young generation should speak out and take actions now.

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