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Trend and Characteristics of Ambient Particles in Seoul

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ABSTRACT

Various aspects of the air quality problems caused by ambient particles in and around the city of Seoul are discussed. First, the trend of the air quality in Seoul over time is investigated along with the types and quantities of energy consumption in Seoul. It was found that the general air quality in Seoul has improved over the last twenty years because of a change in the primary fuel used in Korea. However, the visibility in Seoul, a representation of the ambient particle concentration, is still worse than in other cities in Korea. In the air around Seoul, secondary particle generation might be as important as particles directly emitted from within the city or transported from outside.

Key words: Seoul, Aerosols, Energy consumption, Secondary particles, Air quality

1. INTRODUCTION

At present, a major fraction of Korea's population lives in an urban area. In urban areas, large amounts of energy are constantly used because of a high population density along with the presence of various industrial activities. These factors can cause several environmental problems. Urban air pollution is a major environmental problem around the world. The United Nations Environmental Programme (UNEP) and the World Health Organization (WHO) started a Global Environmental Monitoring System for urban air pollution (GEMS/Air) in 1974 in over 50 cities in 35 countries to address the urban pollution problem (Mage *et al.*, 1996). From their investigations, it was found that air pollution is widespread in urban areas around the world. Also, air pollution is often the most severe in developing countries. To improve the air quality in urban areas, the current status of the air quality in each urban area should be understood. There are several common factors that can cause air pollution problems in urban areas. It is widely believed that the trends in air quality in different cities show a similar pattern. However, there are also some factors that are specific to each individual urban area. When these factors are all understood, appropriate control strategies can be determined and applied.

Seoul and its vicinities take up only 12% of the total national land area in Korea, yet they account for 46% of the total population and the number of vehicles, making the management of urban air quality very difficult. The air pollution level in the region is 1.7-3.5 times higher than the pollution level in other major cities globally. Against these serious challenges, the Korean government has enacted a plan entitled Special Measures for Metropolitan Air Quality Improvement, which includes total air pollution load management, an emission trading system, and the mandatory purchase of low emission vehicles. Such efforts led to the legislation of the Special Act on Metropolitan Air Quality Improvement in December 2003. The plan is to invest six trillion Won (5.2 billion USD) by 2012 to promote the Special Act in stages, which will lead to a substantial reduction of major pollutants, including particulate matters and nitrogen dioxide (MOE, 2007).

In this work, (1) the temporal trend of air quality, especially that of ambient particles in Seoul, is presented and (2) the major factors affecting the airborne ambient particle level in Seoul are discussed.

2. AIR QUALITY TREND IN SEOUL

In Seoul, the capital city of Korea, the concentration of sulfur dioxide (SO_2) in the air was among the highest in the world until the 1980s (Mage *et al.*, 1996). Fortunately, the concentration of SO_2 drastically decreased in the late 1980s and early 1990s as shown in Fig. 1. However, because of an increase in the number of vehicles, the concentration of nitrogen dioxide (NO_2) in the air has not decreased. In spite of the drastic reduction in sulfur dioxide and total suspended particles (not shown) during the past 25 years, the visibility level in Seoul has not significantly increased.

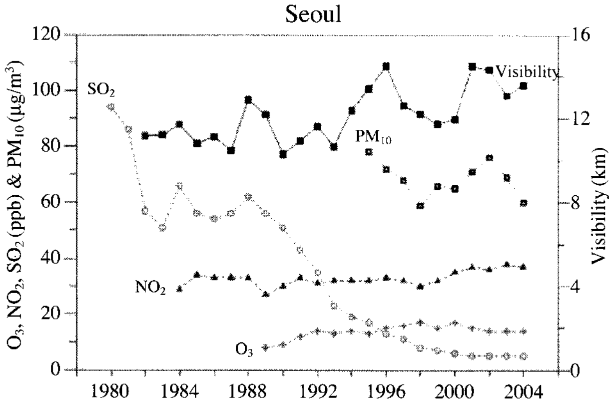

Fig. 1. Trend of the annual average concentration of air pollutants and visibility in Seoul between 1980 and 2004 (Kim, 2006).

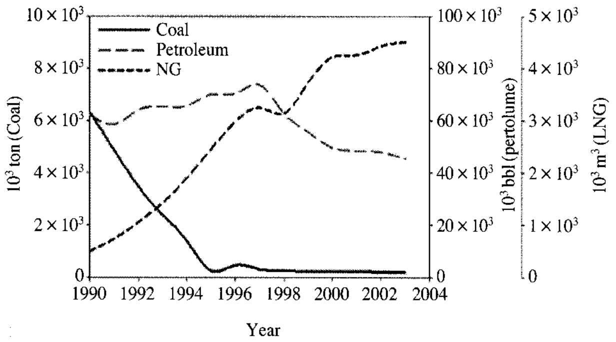

Fig. 2. Trend of fossil fuel consumption in Seoul between 1990 and 2003 (MOCIE, 2004).

This decreasing trend of sulfur dioxide is closely related to the change of primary fuel type as shown in Fig. 2. The Ministry of Environment in Korea has limited the use of solid fuel and heavy oils for heating and cooking in the metropolitan areas of Seoul since 1985 and has strongly enforced the rule since 1995 (MOE, 2005). Thus, the amounts of coal consumption for residential, industrial, and commercial sectors in Seoul rapidly decreased between 1990 and 1995, and the usage of coal has been negligible since 1995. Meanwhile, the amount of natural gas (NG) consumption in Seoul has rapidly increased since 1990. The amount of petroleum consumption in Seoul has not changed significantly since 1990. The main fossil fuels used in Seoul are petroleum for vehicles and NG for residential heating and cooking.

Visibility is an obvious indicator of air quality for the lay person. It is closely related to the mass concentration of particles, especially fine particles. The yearly average visibility decreased nationwide during the 1980s and 1990s, while it increased in Seoul in the 1990s, as shown in Fig. 3. If the visibility is considered to be an indicator of air quality, it can be seen that the air quality in Korea nationwide rapidly degraded in the 1980s and 1990s. In addition, it can be seen that the air quality in Seoul continuously improved in the 1990s (Ghim *et al.*, 2005). This trend in Seoul is consistent with the decreasing trend of PM_{10} concentration in Fig. 1. The fact that the visibility level on a winter morning was lower than in a summer afternoon can be attributed to a higher particle concentration associated with a lower mixing height and higher ambient relative humidity.

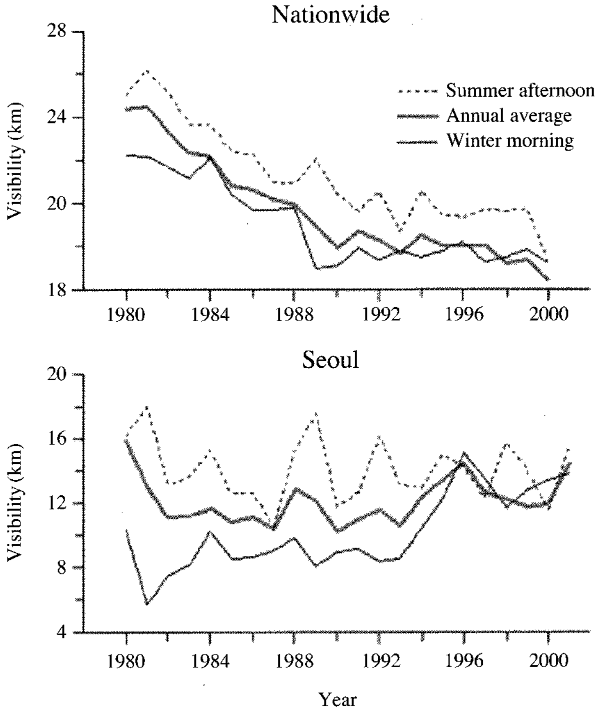

Fig. 3. Trend of visibility in Korea and Seoul between 1980 and 2001 (Ghim *et al.*, 2005).

3. MAJOR FACTORS AFFECTING THE PARTICLE CONCENTRATION IN SEOUL

The mass concentration of particles in the air around Seoul is affected by several processes as shown in Fig. 4. Thus, to develop cost effective control strategies against mass particle concentration, it is essential to identify and quantify the relative contribution of each process. One way of identifying and quantifying the contribution from each process is to use a receptor modeling approach, such as a chemical mass balance (CMB) or positive matrix factorization (PMF)

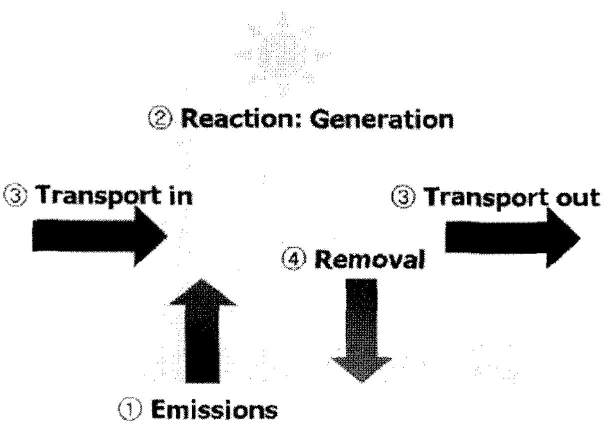

Fig. 4. Schematic diagram of the processes that affect the particulate concentration in the air around Seoul (Kim, 2006).

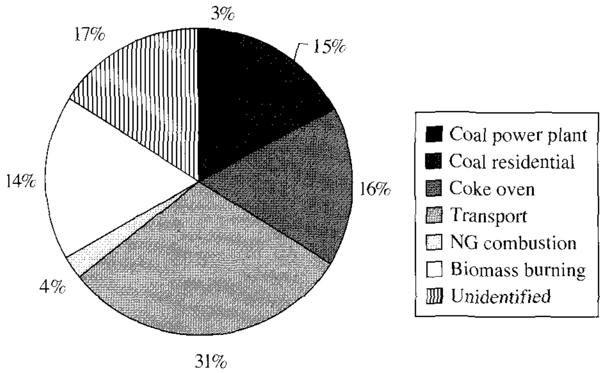

Fig. 5. The fraction of the source contributions for particulate PAHs around Seoul in TSP for the whole sampling period between August 2002 and December 2003 (Lee and Kim, 2007).

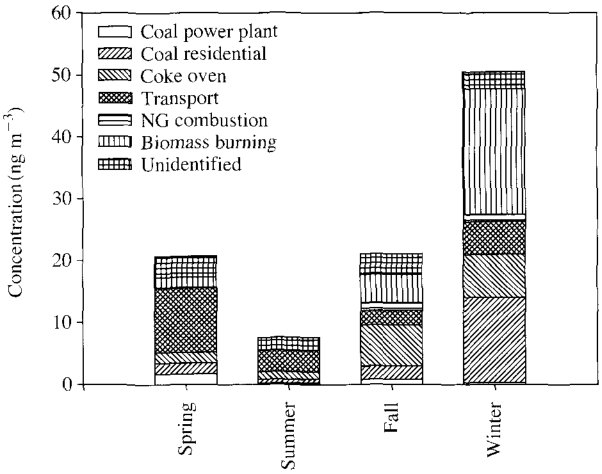

Fig. 6. Seasonal source contributions to particulate PAHs in TSP around Seoul between August 2002 and December 2003 (Lee and Kim, 2007).

model.

It has been speculated that the contribution from outside ('Transport in' shown in Fig. 4) is significant since China and North Korea consume huge amounts of solid fuels, and these are located in areas upwind of Korea. Lee and Kim (2007) have measured the ambient particulate PAH level in TSP in Seoul between August 2002 and December 2003 and applied the CMB model. They found that the major source of particulate PAHs around Seoul over the entire measurement period was gasoline and diesel vehicles, which accounted for 31% of the measured particulate PAHs levels as shown in Fig. 5 (transport). However, the source contributions showed distinct seasonal variations. High contributions of biomass burning and coal (residential and coke oven) were shown in fall and winter and accounted for 63% and 82% of the total PAHs concentration, respectively, as shown in Fig. 6. Since these sources were not strong in and around Seoul, these might be related to transport from outside of Seoul, such as from China and/or North Korea.

Kim (2006) has surveyed previous three receptor modeling results for the $PM_{2.5}$ mass concentrations in Seoul. Those results suggested that (1) the contribution from vehicular emission (gasoline and diesel combined) to the $PM_{2.5}$ mass concentration was 15-25%; (2) secondary particles (sulfate, nitrate, or smog particles) contributed 30-40%; and (3) the contribution from biomass burning or other uncontrolled burning was significant, at about 20%.

One important process that contributes to the particle mass concentration in Seoul is the secondary particle generation in the air. Since these particles are generated in the air, conventional particle emission reduction strategies would not be effective. Major precursors of secondary particles are nitrogen dioxide and volatile organic compounds (VOCs). In addition, these secondary particles can absorb water vapor in the air, and thus the mass concentration can be increased. The chemical reactions and water absorption process are highly non-linear. Therefore, reduction of the emissions of nitrogen dioxide and VOCs might increase the secondary particle formation as shown in Fig. 7. Lee *et al.* (2006) carried out a sensitivity study of fine particle ionic mass and water concentrations to the emission changes of VOCs and NO_x ($NO+NO_2$) in the metropolitan Seoul area using a photochemical box model, SBOX, and a gas/aerosol equilibrium model, SCAPE. Fig. 7 shows the sensitivity of

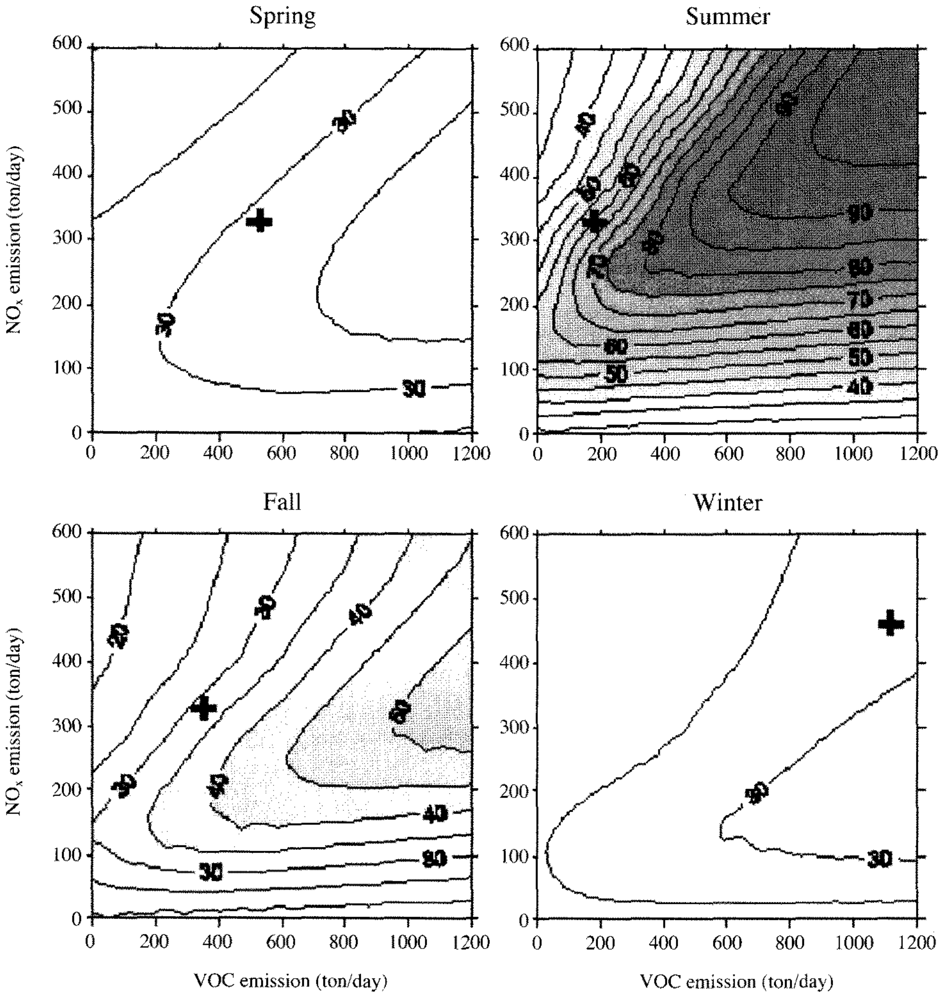

Fig. 7. Isopleths of particle mass (ions plus water) concentration by varying NO$_x$ and VOC emissions. Isopleth levels are given in $\mu g\ m^{-3}$. A cross symbol denotes the base case (Lee *et al.*, 2006).

the particle ionic mass and water concentration as a function of NO$_x$ and VOC emissions. Daily NO$_x$ and VOC emissions varied from 0 to 600 tons and from 0 to 1200 tons, respectively. For all seasons, VOC emission reduction leads to a decrease in particle mass concentration while NO$_x$ emission reduction leads to an increase up to certain point. This phenomenon arises because Seoul is in a VOC-limited or a NO$_x$-excess region, i.e., photochemical reactions in the region are suppressed by high NO$_x$ emission (Lee *et al.*, 2006). Thus, one should be very careful when developing emission control strategies against particle mass concentration.

4. SUMMARY

Based on the available data, it was found out that the air quality in Seoul has improved over the last twenty five years. However, visibility in Seoul is worse than in most large cities in Korea. The mass concentration of particles in the air around Seoul is affected by several processes such as primary emission, secondary generation, and transport from outside, and it is likely that all three processes are non-negligible. Thus, to develop cost-effective control strategies for the particle mass concentration, it is essential to identify and quantify the relative contribution of each process.

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