Study on the Reduction Effect of Nitrogen Oxide Air Pollution by the Roadside 'Green Belt' Zone

Kazuo Ogawa

Summary

In order to ascertain the Nitrogen Oxide air pollution reduction which results from the presence of a roadside 'Green Belt' zone, the following studies were conducted :

1) Actual survey of roadside NOx concentration.

2) Measurement of NO_2 concentration distribution inside and outside Urban parks.

3) Measurement of NO_2 vertical concentration distribution and the production structure for mulberry fields.

4) Measurement of NOx concentration reductions to be found within forest stand.

5) Measurement of air pollution reduction resulting from the presence of the 'Green Belt' zone and explication of this mechanism.

6) Comparative evaluation of 'Green Belt', zoning and other roadside air pollution reduction efforts.

7) Estimate of NO_2 amount absorbed by the plants and trees in Saitama Pref.

The reserch results of the above showed that the NO_2 concentration inside of and behind the roadside 'Green Belt' zone is lower than that of the point in question. It became clear that the diffusion of the automobile exhaustgas in the atmosphere was caused by the 'Green Belt' zone.

Thus, the author came to the positive conclusion that the presence of a roadside 'Green Belt' Zone should be regionally effective as a NO_2 Pollution counter measure .

And outline of the study results follow.

〔 I 〕 State of NOx pollution in roadside areas

In order to ascertain changes in NOx concentration in the vicinity of road, NOx concentration measurement over a two-month period using an automatic measurement instrument and questionnaire surveys of motor vehicle exhaust monitoring stations nationwide were conducted.

1 . Behavior of NOx in roadside areas

(1) NOx and NO_2 concentrations were shown to become distinctly higher upon nearing the road. NOx concentration describes a two-peak variable pattern, as it is high during the morning and evening hours but lower during the daytime, while a look at NO_2 concentration resulting from automobile exhaust gas, varying according to time that reaches the highest level during the daytime, forms a one-peak variable pattern. Furthermore, even areas 85m from the road had NOx concentration of 18ppb and NO_2 concentration of 5ppb higher than the levels from the background areas, thus distinctly exhibiting the effects from automobile exhaust gases.

(2) Roadside NOx and NO_2 concentrations were higher when the quantity of solar radiation and wind velocity were small, in direct proportion to the distance from the road. On the other hand, NO_2 concentration resulting from automobile exhaust gas was higher when the quantity of solar radiation and wind velocity were large. Additionally, the NO/NOx ratio (Y) resulting from automobile

exhaust gas emanating off the road could be obtained according to the equation $Y=0.87X^{-0.025}$, where X is the distance from the roadside.

(3) With the results above it was proved that the effective measures against NO_2 pollution in the visinity of the road are to have one's residence off the road and to check the chemical change from NO to NO_2.

2. Relationship between NOx concentration and traffic load as shown by measurements from Motor vehicle exhaust monitoring stations

According to questionnaire surveys of motor vehicle exhaust monitoring stations nationwide on measurement results, environmental impact and so forth, the following could be shown :

(1) Upon cross-tallying the distance from the road and the traffic load, it was shown that the NOx and NO_2 concentrations grew higher as the traffic increased, while becoming lower as the distance from the road increased. The relationship between NO_2 concentration (Y ; annual mean, ppb) and traffic load (X ; ×10,000 vehicles/12 hr) is shown to be $Y=3.1X+23.5$; thus, a traffic load increase of 10,000 vehicles results in the NO_2 concentration becoming 3.1ppb higher, So, it is very probable that when the NO_2 concentration of the background area is over 23.5ppb, the traffic load is about 20,000 vehicles/12hr, yielding 30ppb up on the road.

(2) NO_2 concentration (Y ; annual mean, ppb) up on the road is related to NOx concentration (annual mean, ppb) according to the equation $Y=2.10X^{0.61}$; in areas with high NOx concentration, NO_2 concentration was shown not to fall too much even when the NOx concentration fell.

3. Relationship between annual mean and Air quality standard of NO_2 in the vicinity of roads

(1) According to NO_2 concentration measurements from motor vehicle exhaust monitoring stations nationwide, the maximum NO_2 health effect criteria for 1990 (annual mean, 30ppb) was 41%, while the maximum NO_2 environmental air quality standard (98% annual based on daily average of hourly values, 60ppb) was 64%, accentuating the difference between the two figures.

(2) The relationship between the NO_2 annual mean (X) and the 98% value (Y) is described by the line $Y=1.51X+5.5$(1988) upon roads with high pollutant concentration. The 98% value on the line equaling the value for 30ppb annual mean is 50.9ppb. This relationship varies according to such factors as NO_2 concentration level and distance the intake nozzle (for the measurement instrument) has been located from the roadside ; the 98% value which corresponds to the annual mean values exhibits a tendency to fall as the distance to the road decreases and the concentration increases.

(3) From above, it is shown that the maximum NO_2 environmental Air Quality standard should be set at least at 50ppb. However, the author views most measurement stations as having criteria below 40ppb, under a standard without consideration of safety margins.

〔2〕 NO_2 air pollution reduction effect of plant community

Although it is clear that plants absorb NO_2, O_3 etc. to help clean the atmosphere, it has not yet been known as to how much 'Green Belt' zones out in the field help to lower air pollution.

The authors therefore decided to measure NO_2, NOx concentrations within and without Urban parks, mulberry fields, substitution forest as well as roadside 'Green Belt' zones, in order to ascertain the decrease in air pollution and to understand the mechanism involved therein.

1. Distribution of NO_2 concentration inside and outside urban parks

In order to ascertain changes in NO_2 concentration distribution inside and outside of the urban parks and their extent resulting from the 'Green Belt' the NO_2 concentration distribution measurement was conducted in two parks.

(1) Although the NO_2 and NO concentration distributions within parks located behind 'Green Belt' zones varied according to such factors as wind velocity, the concentration was lower inside the park compared to outside the park.

(2) In the visinity of the road, NO_2 concentration distribution changed prominently under the influence of the buildings and 'Green Belt' zone.

(3) The air pollution reduction effect of the 'Green Belt' zone was checked using the plume model. Assuming the 'Green Belt' zone to be a 12m wall, the amount of automobile exhaust gas breach upward the zone 60%, the cross-wind effect 50%, wind speed 2m/s and degree of atmospheric stability D, then the NOx concentration fell by 30% at 50m from the roadside. It was found that by increasing the 'Green Belt' zone height and allowing more automobile exhaust gas to breach upward the zone would yield further reduction of pollution on the road.

2. Measurement of NO_2 concentration distribution within Mulberry field

Measurement of NO_2 concentration distribution and stratified clipping was carried out from June to October within a mulberry field.

(1) Dense planting differ from normal planting in community structure. Dense planting has many leaves distribution between the middle and the upper stratum, while normal planting between the middle and the lower stratum. So that, the decrease of NO_2 concentration and the velocity of the wind were large in the upper stratum of the dense planting, but they made a slow decrease from the upper to the lower stratum of the normal planting.

(2) A linear relationship existed between NO_2 reduction rate and the leaf area index (LAI) of the normal planting. NO_2 reduction rate of the dense planting was larger than the normal planting in summer. A major cause for the difference was considered to be the screening effect depending on the community structure.

This result suggests the major possibility that the structure of the 'Green Belt' zone shoud have much effect upon the reduction of NO_2 concentration.

3. Air pollution reduction by Substitution forest

NO_2 concentration inside and outside substitution forest during two different scale were surveyed with automatic measurement equipment, etc.

(1) 0.3ha of substitution forest situated east of a community college in summer had over 20% lower NO_2 concentration in comparison to NO_2 concentration outside the area.

(2) 4.7ha of substitution forest next to Heirinji Temple,over a seven month period from June, had a reduction inside of NO_2 and NO concentration of 15.2% and 7.6%, respectively, during the 'N−wind' time period when the road effect was minimal. (Henceforce referred to as 'N-wind time-period data'.) Moreover, night time NO_2 reduction rate was 19.1%, approximately twice the rate during daytime. According to month, NO_2 reduction rate was highest in August at 21.3%, approximately twice the rate in December of 10.1%.

(3) From NO_2 concentration changes inside and outside substitution forest as well as analysis there of, the reduction effect of NO_2 and other concentration was shown to depend more on the plant community structure, NO_2 concentration in the area, etc. in addition to affective factors such as weather conditions, rather than on just the absorption capacity of plants. In general, plants exchange gases actively when the sunlight is strong and temperature high. However, as conditions in the field, the same conditions affect the air pollution and pollutant concentration thereof, the variation in concentrations inside and outside plant community is greatly influenced by weather conditions, plant community structure as well as individual plant activity efficiency.

4. Survey on roadside 'Green Belt' zone air pollution reduction.

In order to ascertain air pollution reduction effects of roadside 'Green Belt' zones, NO_2 concentration was measured continuously both inside and outside the Ageo Exercise Park and the Yono Park.

(The Ageo Exercise Park 'Green Belt' zone made up of ever green trees surrounding the road)

(1) According to NO_2 concentration distribution survey, using the personal sampler, though some places on the western side of the road showed no reduction in concentration, the 'Green Belt' zones there being 'Spotty', the dense and continuous zone on the eastern side showed a reduction, illustrating the fact that the structure of the zone influences the reduction results.

(2) On the average, the measurement of the automatic equipment over a seven-month period showed that within the 'Green Belt' zone, NO_2 was 4.1ppb and NO 4.3ppb, lower than the control area in question with reduction rates of 14.1% for NOx and 10.3% for NO

(3) According to month, NO_2 concentration within the 'Green Belt' zone was low compared to the control area, by 6ppb in November and December at most, by 2ppb in Augusts as least. In terms of Percentage, October had the highest with 17% reduction rate, August the lowest, at 11%.

(4) The ratio of low wind condition periods (calm;below 0.3m/s wind speed) had NO_2 reduction rate of 27% in July, NO reduction rate of 36% in June as highest figures, with these falling somewhat from fall to winter.

(5) Amount of NO_2 absorption rate of the 'Green Belt' zone was 0.9 to 1.6% that of NOx from vehicles on the road, falling below the NO_2 reduction rate.

(6) Reduction rates for NO_2 and other concentrations changes according to wind directions. During periods of road cross-winds or calm, the NO_2 and NO concentrations rose in the top foliage. Upon headwinds, the 'street canyon effect' took place to reduce the reduction rate.

(7) The result above seem to indicate that the air pollution reduction effect of the 'Green Belt' zone is attributed to the sheltering quality of the 'Green Belt' zone structure and its accompanied effect of diffused automobile exhaust gas in the atmospher as well as the direction of wind.

(Yono Park 'Green Belt' zone made up of deciduous trees situated along the one side of the road.)

(1) On the average, the seven-month period from June showed that within the green belt, NO_2 was 2.7ppb and NO 1.4ppb lower than the control area, with NO_2 and NO reduction rates at 7.0% and 2.2%, respectively. NO_2 concentration within the 'Green Belt' zone was higher than the control area in July -1.5% in terms of reduction ratio, while other months had lower concentrations, with September having the highest reduction ratio of 12.9%. NO concentration within the 'Green Belt' zone was higher than the control area for the months of June, July, August, and November, having negative reduction rates, with August having 14%. The best reduction rate was 7.7% in September.

(2) Upon finding the location wise concentrations and reduction rates for August and November, the NO concentration in the top area surpassed the figure for the control area during road cross winds conditions, resulting in upward redirection of layer by the 'Green Belt' zone, with the zone sometimes filling up with NO. On the other hand, NO_2 concentration fell for both months under windy conditions, but the topmost layer had a higher NO_2 concentration in comparison to the control area layer in August, while November. found the concentration to be about the same.

(3) The long-term NO_2 concentration reduction average was noted in the zone, but because of the many gaps with the 'green Belt', the results varied greatly according to weather conditions bringing in automobile exhaust gases.

(4) NO_2 reduction result in the 'Green Belt' zone monthly changes atmospheric stability and O_3 concentration were considered, showing variations according to 'Green Belt' structure, atmospheric diffusion balance, and the fact that O_3 concentration led to NO_2 production changes.

Thus, the air pollution reduction aspect of the 'Green Belt'zone would be influenced by the structure of the 'Green Belt'zone, and this should be kept in mind.

Main reasons for air pollution reduction effect by 'Green Belt' zone from the results above, It has been shown that by adjusting the distance to the 'Green Belt' zone from the roadside, the effects of automobile exhaust gases could be lowered while concurrently directing a portion of the gases upwards; as for the remaining gases going into the 'Green Belt' zone could also be reduced by the low wind velocity, just as the NO_2 concentration fell behind the 'Green Belt' zone on the average. Further, NO_2 production was held back by the reduced O_3 concentration within the zone, thereby lowering NO_2 concentration, but effected the 'Green Belt' zone structure and weather conditions which flow conditions inside and outside the zone could sometimes lead to increase NOx concentration due to automobile exhaust gas influx into the 'Green Belt'zone.

5 . The amount of NO_2 absorbed by the plants and trees in Saitama Pref.

(1) In proportion to the NOx exhaust level, the rate of NO_2 absorbed by the plants in Saitama Pref. was about 7%.

(2) Consequently, the concentration of NO_2 in the atmosphere was estimated to be lower by about 1.26ppb on average.

6 . Comparison of major pollution reduction plans

NO_2 concentration fell by 4.1ppb (14%) in Ageo and 2.7ppb (7%) in Yono due to the roadside 'Green Belt' zones. Although absorption ratio by the plants were small and the areas was limited, it was seen to be and effective countermeasure against high NO_2 concentration pollution of main artery roads.

In order to obtain comparable results, the traffic load in Ageo and Yono must be reduced, through out the year, by 50% and 18%, respectively.

Also, even if the traffic speed were increased by 10km/hr, the NO_2 concentration would only fall by 3%, and anyhow such an increase in speed can only be attained with a considerable reduction in the amount of traffic. As for automobile emission control, the time-lags involved neutralized the measures, leading to the current NO_2 concentration overload situation.

Thus, it can be seen that just one roadside NO_2 pollution countermeasure was not enough to combat the current problem. A comprehensive strategy of combining various countermeasures is needed to improve the efficacy of these plans, with the effective use of the 'Green Belt' zone being one of the major countermeasure plans now available.

7 . The possibility to predict the NO_2 concentration reduction by the 'Green Belt' zone

Because the 'Green Belt'zone is complicated in structure,it was been considered difficult to predict the reduction of NO_2 concentration by means of conventional diffusion model.

Never the less the predictability of the forcast will be enhanced by increasing the number of measurement as shown in the examples predicted by the equation from experience.

8 . The conditions for a roadside 'Green Belt' zone as NO_2 pollution countermeasures

The condition for a roadside 'Green Belt Zone' as a NO_2 pollution countermeasure should be coordinated in conjunction with the surrounding environment as follows,

① The 'Green Belt Zone' should be continuous without break.

② The majority of trees in the 'Green Belt' zone should be tall ever greens.

③ The 'Green Belt' zone on the roadside should be covered with planted ever green trees.

With the conditions above, the author would like to suggest that it would be best to plant trees in combination with deciduous trees and so forth, depending on the size of the space.