6.8 Emission factors for atmospheric pollutants

6.8.1 Outline [1]

In order to rationalize the air pollution counter measures in a given region, it is essential to estimate the total quantity of air pollutant emissions by kind of pollutant as well as human activities. For this estimation, the air pollutant emission factors calculated from air pollutant emission due to human activities such as fuel combustion or industrial production and these activities have been utilized. Further, this technical constant, which are necessary for estimating the total regional emissions of air pollutants, can be used to predict the concentration of air pollutants by means of the theory of atmospheric diffusion, and are also employed both in establishing plans for the regional reduction of air pollutants emission and in the running of environmental impact assessment systems.

In 1970, the government of the United States of America announced the estimation results of total amount air pollutant emissions on fire kinds of pollutants in nation wide in 1968 [2]. Further, the American government issued a report [3] by R. L. Dupley concerning the air pollutant emission factors that considered these calculation standards, and which were translated into Japanese by the Japanese Fuel Association [4]. In this report, R. L. Dupley defined the emission factor as follows: "The emission factor for air pollutants is a statistical average of the rate at which a pollutant is released to the atmosphere as a result of some activity, such as combustion or industrial production. The emission factor thus relates the quantity of pollutants emitted to some indicator such as production capacity, quantity of fuel, or vehicle miles traveled by autos." thereby introducing both the overview of causes that generate air pollutants such as fuel combustion, various manufacturing processes, means of transport, and so forth, and the emission factors that they cause. Further, in the introduction to this report [3], Dupley wrote that this collated data from already-published technical papers, and that the calculation basis had been compiled and edited by M. Mayer in 1965 [5].

On the other hand, the MITI, Agency of Industrial Science and Technology in Japan examined the state of smoke and soot emissions from 271 plants nationwide in 1960, and published their results in 1961, but in this report [6], the quantity of soot and dust emissions from cement kilns was calculated as the quantity of soot and dust emissions per cement clinker production t. That result was 0.3 to 3.3 kg/t, and stated that with the wet process, there were many cases where the results were 1.8 kg/t or less, and with the dry process, there were many cases where the results were 1.0 to 3.3 kg/t, and that although no specific air pollutant emission factor was included, it can be inferred from the American government that this concept was held from the first. In spite of which, there have been no similar activities by MITI to be seen since.

At any rate, in the same way as the American government, which was noted previously, the MITI report [6] also based its calculations on a air pollutant concentration in exhaust gas that had already been measured, but thereafter, in the 1970s when the emission factor was considered important in Japan, no technical reports concerning the sources of air pollution source were to be seen, and the formation of an independent organization for actually measuring this data deserves special mention.

6.8.2 Air pollutant emission factors from stationary sources

(1) Calculating air pollutant emission factors from stationary sources in Japan

It was when the environmental pollution control programs were planned in 1970 that the total quantity of emissions of air pollutants in a fixed region in Japan were estimated, but if taken separately from the aforementioned production and technology unit's report [6], the emission factors collated from the actually measured data can be said to be the first ever for Tokyo [7].

In 1971, the pollution control bureau for Kanagawa Prefecture obtained formulae pertaining to the emission of sulfur oxide and the quantity of heavy oil burnt in 40 major factories in both Kawasaki and Yokohama cities, and introduced regulations for reducing the total quantity of sulfur oxide using a proportional model, and these relevant formulae can also well be called emission factors [8) 9)].

In 1972, the Air Quality Bureau, Environment Agency established the "Investigation Committee for Air Pollution Due to Photochemical Reaction," added the "Emission Source Sub-Committee," and began examining and investigating on the air pollutant emission factors from stationary combustion sources [1) 10)]. As stated previously, this activity led to the formation and promotion of an independent organization for the measuring of air pollutants in exhaust gas, and this led to its continuation, in 1973, as the "Investigation Committee for Source Generation Air Pollution" [1]. Next, in 1976, measurement data was also collected by local governments and, for example, the relationship between nitrogen oxides emissions and the amounts of burning of fuel was established with regard to power plant and industrial boilers, as shown in Fig.6.8.1. Further, the formulae pertinent to such load fluctuations, emissions of NOx, and quantity of fuel combustion were also established, and the emission factors for NOx concerning boilers were also obtained, as shown in Table 6.8.1. Moreover, the mean proportion of fuel combustion and emissions relating to soot and dust, NOx, CO, and hydrocarbon species was calculated both by fuel and by type of source and, for example, the emission factors as shown in Table 6.8.2 were analyzed [1) 11-13)].

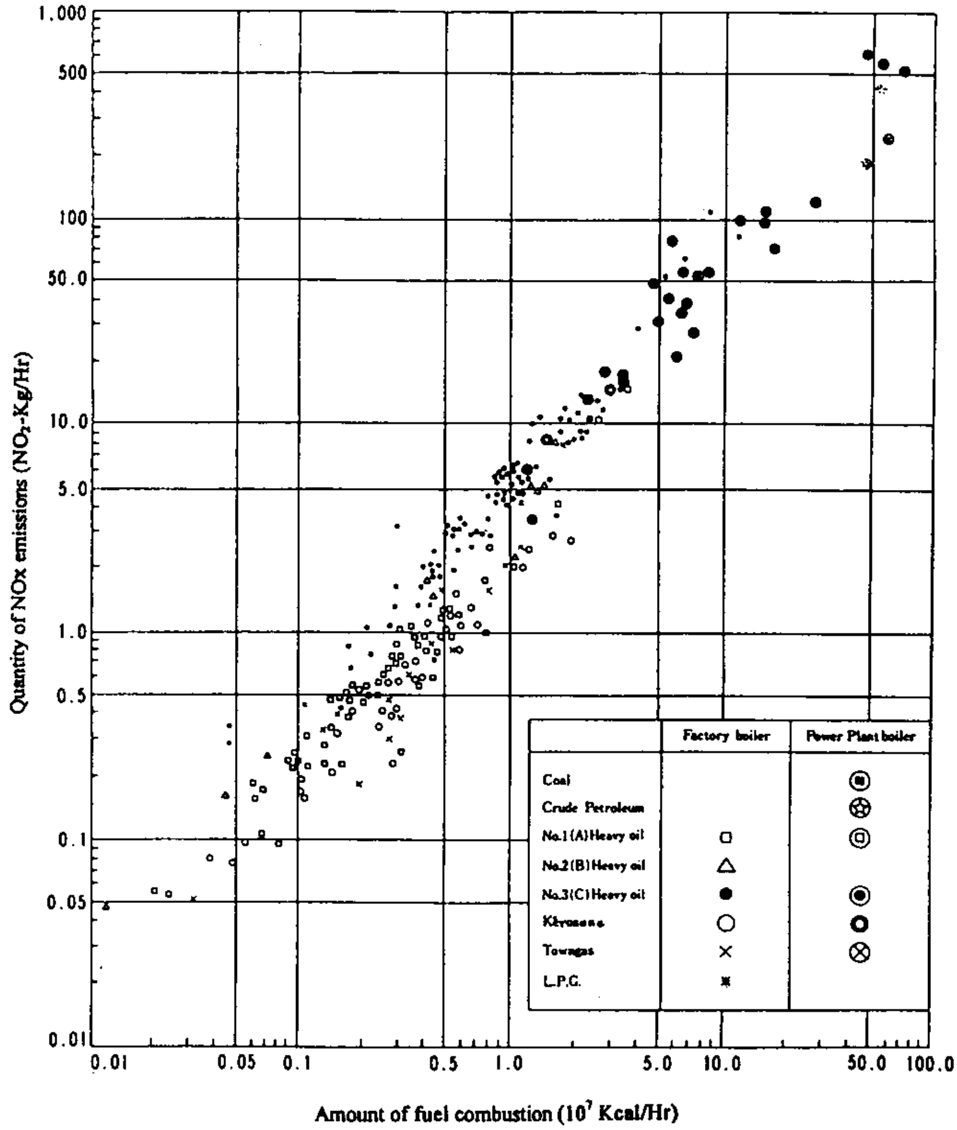

Fig.6.8.1 Relationship between quantity of NOx emitted by industrial boilers used in power generation and amount of fuel combustion.

Table 6.8.1 Emission factors for NOx from industrial boilers and power plant.

Rating of fuel combustion	NOx emission factor (NO_2-Kg/10^8 Kcal)			
(10^7 Kcal/h)	Load 0.4	Load 0.6	Load 0.8	Load 1.0
10	49.1	57.3	64.1	69.8
30	49.7	58.1	64.9	70.7
50	50.0	58.5	65.3	71.2
70	50.2	58.7	65.6	71.5
90	50.3	58.9	65.8	71.7
100	50.4	58.9	65.9	71.8

Table 6.8.2 Examples of emission factors from stationary combustion sources

Combustion facilities	Kind of fuel	Emission factor ($Kg/10^8$ Kcal)			
		Soot and dust	NOx	Carbon monoxide	Hydrocarbons
Power-plant boiler	C heavy oil	4.7	63.5	78.9	37.1
	A heavy oil		50.7		
	Crude oil		56.5	3.3	89.0
	LNG		38.9		
	Coal		128.0		
Industrial boiler	C heavy oil	12.2	56.6	7.5	0.11
	B heavy oil	5.9	40.5	7.1	1.12
	A heavy oil	6.4	25.2	3.5	0.43
	kerosene	5.6	20.7	17.3	0.08
	LPG		32.4		0.09
Glass melting furnace	C heavy oil	48.1	251.0	32.5	0.25
	B heavy oil		257.0		
	A heavy oil	2.4	121.0		
Cement kiln Dry process	C heavy oil	9473	127.0	83.2	4.64
Wet process		11782	162.0	12.2	1.63
Lepol		14414	212.0	246.0	1.42

(2) Examples of calculated results of air pollutant emission factors

Thereafter, the government of the United States of America also calculated the emission factors for many different air pollutants, and published their findings [14]. These examples are shown in Table 6.8.3 and 6.8.4 [14].

Table 6.8.3 Emission factors for stationary combustion sources (Fuel oil burning, no controls)

		Soot and dust	Sulfur dioxide	Anhydrous sulfuric acid	Carbon monoxide	Nitrogen oxides
		(amount of air pollutants emitted − Kg/Amount of fuel oil firing-kℓ)				
Boiler type	For power generation (Heavy oil firing)		19S	0.34S	0.6	8.0
	For industrial use (Heavy oil firing)		19S	0.24S	0.6	6.6
	For industrial use (Kerosene firing)	0.24	17S	0.24S	0.6	2.4
	For commercial use (Heavy oil firing)		19S	0.24S	0.6	6.6
	For commercial use (Kerosene firing)	0.24	17S	0.24S	0.6	2.4
	For domestic use (Kerosene firing)	0.3	17S	0.24S	0.6	2.2

Note: S: Sulfur content in the fuel (%)

Table 6.8.4 Evaporation loss of hydrocarbon from gasoline supply

Emission source		Emission factor (Emitted gasoline vapor-mg/Amount of gasoline fuel-l)
Supplied by underground tank	Splash fill (On the supply pipe surface)	1440
	Submerged fill	840
Underground tank venting loss		120
Automobile tank fuel supply loss		
(No control)		1320
(Control)		132
Spillage		80

(3) Use of emission factors of air pollutants relating to stationary sources

Thereafter, the emission factors shown in bothTable 6.8.1 and in Table 6.8.2 were used in estimating the total quantity of air pollutant emissions of NOx, etc., in Japan nationwide [1] and, moreover, were used in establishing a plan for reducing the total emission of NOx, thereby proving to be very useful to Japan in her pursuit of air pollution control programs.

Further, as was stated previously, the emission factors have also been used in creating a regional diffusion model [15] for air pollutants, in order to evaluate the environmental impact.

6.8.3 Air pollutant emission factors from mobile sources [16]

The quantity of air pollutant emissions from automobiles differ depending upon the model of car (engine type [gasoline, diesel], size [weight of vehicle, load] quantity of exhaust), running type (driving pattern), and type of exhaust gas control measures. These different factors are made as equitable as possible, the overall composition is thoroughly understood, and the emission factors are vitally important as basic data for calculating the proportion that different types of vehicle contribute to pollution.

(1) Relation between driving and air pollutant emissions (general trends)

The general trends of the relationship between driving and air pollutant emissions are shown in Table 6.8.5. Moreover, for calculating the emission factors, it is vitally important to thoroughly and effectively understand the mean of the types of vehicle, chassis weight, load, emissions, and driving pattern.

Table 6.8.5 Relation between air pollutants and driving

CO, HC, Fuel costs	Depends on mean vehicle speed.
Diesel vehicle NOx	The quantity of low speed emissions during urban driving is high. On the expressway, however (when there are no traffic jams), conversely, the quantity of high speed emissions is high.
Gasoline vehicle NOx	Does not rely heavily on mean vehicle speed. At times of high load (during acceleration, during high speed driving), emissions are high.

(2) Overview of the procedure for calculating emission factors

In order to calculate the emission factors, first of all a survey is taken of the actual driving used by test cars on roads in the area targeted for calculation, and the driving results obtained are analyzed and a representative driving pattern compiled.

Next, the calculations of the emission factors for the target vehicle are set on the chassis dynamo meter, the compiled driving pattern is recreated and, during a mock run, the quantity of atmospheric pollutants emitted in the exhaust gasses is measured. In addition, the measurements obtained are collated and analyzed, and the emission factors thereby calculated.

(3) Actual driving survey using test vehicles in the target area

An actual driving survey is conducted using a test vehicle with the aim of understanding the automobile driving conditions on roads in the area targeted for calculating the emission factors. The driving method used follows regular automobile driving trends, the test vehicle is driven, and vehicle speed the idling time, cruise time, amount of both acceleration and deceleration in time blocks of, for example, every 0.5 seconds are recorded. And both the running time and roads are considered under multiple traffic conditions before a decision is reached.

(4) Driving pattern sampling

A sample of the mean driving pattern (taken to be approximately 20 minutes of ordinary driving) for vehicle speed, idling time, cruising, amount of both acceleration and deceleration, and the time period is taken from the results recorded above. In addition, in the case of Tokyo, a single pattern is sampled for the urban expressway, and the mean of 10 patterns (4.5 to 45.0 km/h) sampled for ordinary roads.

(5) Experiments to measure exhaust gasses from the chassis dynamo meter

The representative driving pattern is recreated on the chassis dynamo meter, a mock test run is conducted, and the exhaust gasses are analyzed and measured. The model of vehicle measured is selected following consideration of the type of vehicles driven in the survey test area. In addition, the chassis dynamo meter is fixed to a roller device on the automobile motor axle, the driving pattern is established, and the device recreates engine running conditions while the vehicle in question remains stationary. Although there is running resistance to the roller, the load that the mechanism bears depends upon the vehicle speed. Because running resistance differs depending on the model of the vehicle, if the running resistance in question is discordant, then actual measurements are necessary.

(6) Compiling emission factors

The measurement results are adjusted depending on the model of car. In addition, if the test is held in Tokyo, a regression curve is normally taken to be the emission factor. Fig.6.8.2 shows the results of emission factors calculated for NOx in Tokyo in 1994.

(7) Calculating air pollutant emissions

The emission factor for automobiles is always represented as (g/vehicle·km). In addition, there are many times when "vehicle" is omitted. Moreover, in order to calculate the quantity of emissions, the model of vehicle (vehicle·km/h) corresponding to the emission factor is necessary. The method for calculating (vehicle·km/h) is to identify the amount of traffic (y vehicles/h) over a fixed distance (x km), and to then multiply these to obtain (x·y vehicles km/h), namely, the total quantity of air pollutant emissions is obtained by Eq. (1) and (2).

Quantity of emissions per model of car (kg/h) = fixed distance (x Km) × amount of traffic per model of car (y vehicles/h) × emission factor per model of car (g/vehicle·Km) ·· (1)

Total quantity of emissions (Kg/h) = model A(Kg/h) + model B (Kg/h) + ··· ·················· (2)

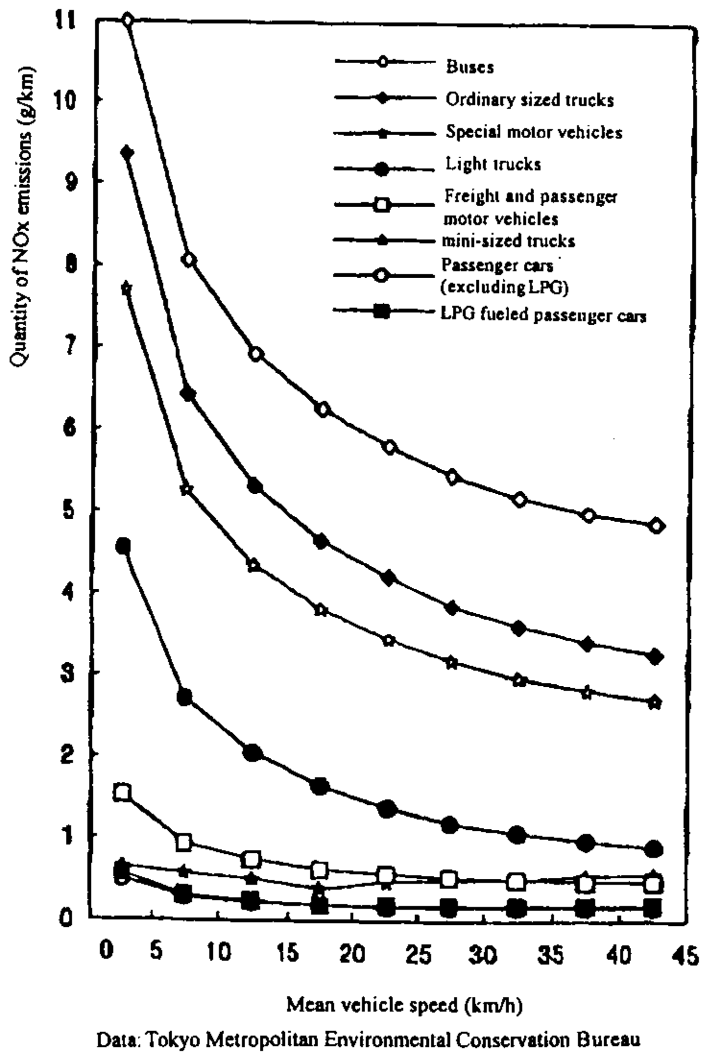

Fig.6.8.2 NOx emission factors (fiscal 1994)

(8) General noteworthy items

Because the emission factors are both regional and mean values, in order to use a fixed route and time period, it is necessary to be cautious. Because the emission factors are necessary to the very end for calculating the quantity of emissions, if such data as, for example, the amount of traffic, necessary for these calculations is insufficient, no matter how great a level of accuracy is demanded, it is virtually meaningless, or else have to be taken as the units of the emission factors that correspond to the amount of traffic flow data.

(6.1) Literature cited

1) Kurokawa,M.; Combustion Engineering, pp.1-14, Gihodo (1953)
2) Tsuji, S.; Combustion Technologies for Environmental Protection, Association of Japanese Thermal Energy Technology (1973)
3) Shibata, K.; Power Station and Substation, Denki Shoin (1972)
4) Air Quality Bureau, the Environmental Agency of Japan; Report on the Air Pollutant Emission Factor from Stationary Combustion Sources (1977)
5) Himi, Yasuji; Future of Air Environment Protection and the Role of Science and Technology, J. of Environmental Pollution Control, 21, 310-312 (1985)
6) Hagiwara, H. and Tamaki, T.; MHD Power Generation, Sogo Kagaku Shuppan (1975)

(6.2) Literature cited

1) Japan Society of Powder Technology Ed.; Dictionary of Particle Engineering Terms, Nikkan Kogyo Shinbunsha (1981)
2) Air pollution control division, Air Quality Bureau, the Environmental Agency of Japan, Ed.; Explanation of Dust Generating Facility, Gyousei (1985)
3) Hatta, S.; Introduction to Chemical Engineering, Kyoritsu Shuppannsha (1951)
4) Himi, Y.; On the Air Pollutant Emission Factors from the Stationary Sources, *J. Japan Soc. AirPollut,* 21, 465-485 (1986)

(6.3) Literature cited

1) Air Quality Bureau, the Environmental Agency of Japan; Report on the AirPollutant Emission Factors from Stationary Combustion Sources (1977)
2) Ministry of International Trade and Industry; Industrial Location and Environmental Protection Bureau ed., Law and Technology of Environmental Protection, Industrial Pollution Control Association of Japan (1978)
3) Himi, Yasuji; On the Air Pollutant Emission Factors from the Stationary Sources, J. Japan Soc. AirPollut, 21, 465-485 (1986)
4) R.L. Duplay, Trans. Fuel Association; Sources of Air Pollutant-Formation Process and Emission Factor-, Yokogawa Shobo (1971)
5) Shoji, T.; Acid, Alkali and Fertilizer, Sangyo Tosho (1948)
6) U.S. Environmental Protection Agency; Atmospheric Emissions from Chlor-Alkali Manufacture (1971)

(6.4) Literature cited

1) Iwasaki, J.; Applied Mineralogy, Uchida Rokakuho (1943)
2) Air Quality Bureau, the Environmental Agency of Japan; Report on the Emission Factor of Air Pollutant from Stationary Combustion Facilities, pp.312-313 (1976)
3) Himi, Y.; On the Air Pollutant Emission Factors from the Stationary Sources, *J. Japan Soc. AirPollut,* 21, 465-485 (1986)

4) J.J. Schneneman, W.D. High, W.E. Bye; Air Pollution Aspect of the Iron and Steel Industry, U.S. Department of Health Education and Welfare, Public Health Service (1963)

5) Tanabe, T. et. al. trans.; Shlaeger, Introduction to Metallurgy, Maruzen (1971)

6) Morinaga, T.; Aluminum Refinery, Nikkan Kogyo Shinbunsha (1968)

(6.5) Literature cited

1) Igi, S.; Natural Petroleum and Artificial Petroleum, Kyoritsu Shuppan (1952)

2) Iwamoto, S., Trans.; Fundamental Chemistry for Understanding Environment, Tokyo Kagaku Dojin (1989)

3) The Japan Petroleum Institute, ed.; Oil Refinery Process, Revised, Miyuki Shobo (1972)

4) Morita, Y.; Petroleum Refinery-Theory and Engineering, Shokodo (1972)

5) U.S. Department of Health, Education, and Welfare, Public Health Service; Atmospheric Emission from Petroleum Refineries, A Guide for measurement and Control (1960)

6) Himi, Y.; On the Air Pollutant Emission Factors from the Stationary Sources, *J. Japan Soc. Air Pollut*, 21, 465-485 (1986)

7) Nippon Sekiyu Co., Ltd.; Petroleum Handbook 1994, p.245 (1994)

8) The Japan Petroleum Institute, ed.; New Encyclopedia of Petroleum, p.857 (1992)

(6.6) References

1) Air Quality Bureau, Environment Agency; Motor Vehicle Environmental Pollution Control in Japan, July 1996.

2) The Tokyo Metropolitan Research Institute for Environmental Protection; Air Pollution by Motor Vehicle Exhaust Gas, Environmental Topic Series No.8, 1995.

3) Bureau of Environmental Protection Tokyo Metropolitan Government; The Report of Vehicles Total Distance Traveled, and Amounts of Pollutants Emitted from Vehicles in Tokyo (Summary Estimate) March 1996

(6.7) Literature cited

1) Yamamoto, Shinichi; Improving the Offensive Odor and related Laws, *Environmental Management* 32, 137 to 144 (1996)

2) Kuratani, Hidekazu; Recent Trends in Offensive Odor Complaints, *Industry and Environment*, March issue, 57 to 60 (1997)

3) Offensive Odor Law Research Council; Offensive Odor Control Law Handbook, Revised Edition, Gyosei (1996).

4) New Environmental Management Facilities Lexicography Committee; Air Pollution Prevention Equipment, Industrial Survey Council (1996)

5) Takahashi, Masahiro; Status of Offensive Odor Problems in Sewage Treatment Plants, *Offensive Odor Research* 25, 1 to 7 (1994)

6) Tanigawa, Sho; Status of Preventive Measures Against the Generation of Offensive Odors Concomitant with

Urban Waste Processing and Disposal, *Offensive Odor Research* 27, 1 to 8 (1996)

7) Tazawa, Shinji; Preventive Measures Against Offensive Odors in Oil Refineries, *IndustrialPollution* 29, 430 to 436 (1993)

8) Yoshimura, Tsunenori; Preventive Measures Against Offensive Odors in Chemical Plants, *Industrial Pollution* 29, 437 to 442 (1993)

9) Ohgoshi, Yoshio; Preventive Measures Against Offensive Odors in Sewage Facilities. *Industrial Pollution* 29, 443 to 455 (1993)

10) Ishikuro, Ryukichi; Basic Preventive Measures Against Offensive Odors and Current Reality, Ohm Co., 1997

(6.8) Literature cited

1) Himi, Yasuji; On the Air Pollutant Emission Factors from Stationary Sources, *Journal of Japan Society for Atmospheric Environment*, 21, 465-485 (1986)

2) U.S. Department of Health, Education and Welfare, Public Health Service ; Nationwide Inventory of Air Pollutants Emissions 1968 (1970)

3) Dupley, R.L.; Compilation of Air Pollutants Emission Factors, U.S. Department of Health, Education and Welfare, Public Health Service, Bureau of Disease Prevention and Environment Control, National Center for Air Pollution (1968)

4) R. L. Dupley (author), Japanese Fuel Association (trans.); Sources of Air Pollutants-Generation Process and Emission Factors (1971)

5) Mayer, M.; A Compilation of Air Pollutants Emission Factors for Combustion Process, Gasoline Evaporation, and Selected Industrial Processes, U.S. Department of Health, Education and Welfare, Public Health Service, National Center for Air Pollution (1965)

6) Agency of Industrial Science and Technology; Report on Survey into Soot and Dust (1961)

7) Tokyo Metropolitan Pollution Bureau Regulation Department; Survey into Calculations of Air Pollutant Emission Coefficients (Stationary Sources) (1973)

8) Kanagawa Prefecture Pollution Prevention Bureau; Kanagawa Prefecture Pollution Prevention Prescriptions, etc., Point-by-Point Explanation, Imperial Local Government Association (1972)

9) Himi, Yasuji; Results of Air Pollution Control Measures in Kanagawa Prefecture, *Industrial Pollution*, 16, 461-469 (1980)

10) Japan Thermal Energy Technology Association; Report of Survey into Pollutant Sources Caused by Photochemical Reactions, Quantity of Emissions of NOx and Hydrocarbon Species in Stationary Combustion sources, 1972 Environment Agency-Entrusted Survey (1973)

11) Air Quality Bureau, Environment Agency; Report of Survey Regarding Air Pollutant Emission Factors from Stationary Combustion Sources (1976)

12) Himi, Yasuji et. al.; Air Pollutant Emission Factors from Stationary Combustion Sources, Proceedings of The Fourth International Clean Air Congress, pp.913-918 (1977)

13) Himi, Yasuji; Air Pollutant Emission Factors from Stationary Combustion Sources, Extended Abstracts, Japan-China Symposium on Air Pollution, pp.173-178 (1991)

14) U.S. Environmental Protection Agency; Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point And Area Sources, Fourth Edition, pp.1.3-1, pp.4.4-15 (1985)

15) Himi, Yasuji; Responses to Regulation of Total Emission of NOx, *Energy Saving*, 10, (7) 10-17 (1983)

16) Tokyo Metropolitan Pollution Bureau Air Quality Department; Vehicle Pollution Handbook (1980)