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Pollution of Polyaromatic Hydrocarbons in the Airborne Particles in the Developing Countries in Asia Region

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1. Introduction

Polyaromatic hydrocarbons (PAHs) which is one of the environmental pollutants are originated from mainly two sources. One of them is combustion source, and PAHs form by imperfect combustion of coal, petroleum, etc. Therefore, the pollution affects widespread. The another is petroleum itself, and the PAHs are released by marine accidents of ships and ocean disposal. Furthermore, the natural PAHs also exist. For example, perylenequinon pigment is a source of perylene[1].

It is well known that most PAHs are carcinogenic and mutagenic[2]. In Japan, the Air Pollution Control Law has been revised in 1996, 234 chemicals are put on the list of harmful substances for the human health[3].

Most PAHs which is carcinogenic and mutagenic have 6-aromatic rings, are high molecular weights and have low vapor pressure, such as benz[a]pyrene (BaP), benzo[b]fluoranthene(BbF), benzo[k]fluoranthene(BkF), chrycene and benz[a]anthrathene(BaA). Therefore, these

exist as the particulate matter in the environment[4,5]. The PAHs in the atmosphere have been measured in the urban area and industrial area in the developed countries from 1970s. In recent years, also in the developing countries, such as China [6,7] and Viet Nam [8], the PAHs have been measured.

In Viet Nam, the number of motor bikes quickly increased in the urban area such as Ho Chi Minh, and the pollution becomes very serious. Further, in Kathmandu, capital of Nepal, the exhaust gas from the primitive cars and flue gas from brick factories are the main sources of pollution. Kathmandu City is located in the Kathmandu Valley, and the air becomes very stable in winter, and therefore, the pollution in the city is very serious. It is an urgent need to understand the actual condition of these cities.

In the present study, the measurement of particulate matters and PAHs in them were carried out for one year. The measurements were also carried out in Osaka City and Shijyonawate City for comparison. The 65 compounds were

Table 1 List of sampling locations

city	site		sampling period
Kathmandu	Monitoring Station in Padan	ambient air	Jan./2003-Dec./2003
Ho Chi Minh	Vietnam National Univ. of Ho Chi Minh	ambient air	Jan./2003-Jul./2004
Osaka	Environmental Pollution Control Center, Osaka Pref.	ambient air	Apr./2001-Mar./2002
Shijonawate	Monitoring Station	road side	Apr./2001-Mar./2002

determined to make discussions of sources and characteristics of the each city.

2. Experimental

2.1 sampling

The sampling locations are summarized in Table 1. The frequencies of sampling are once a month in Kathmandu City, Osaka City and Shijyonawate City and 1-3 times in Ho Chi Minh City. The data of November, 2003 and March, 2004 are missing.

The sample in Kathmandu were obtained by using a PM₁₀ automatic sampler which are placed in the monitoring station with the quartz fiber filters at 38.3 mL/min of the sampling flow rate for 24 hours. The all sample was offered from the EPA of Nepal. In Ho Chi Minh, Osaka City and Shijyonawate City, the sample was obtained by using a hi-volume air sampler with a quartz fiber filter at 0.7 -1.0 m³ / min for 24 hours.

2.2 Reagents

The standard PAHs are obtained from Wako Pure Chemicals, Supelco, Aldrich Chemicals, Tokyo Kasei, Ishidu

Medicals, Nakarai Chemicals, ICN Biomedicals, Acros Organics, Alfa Aesar and Chiron AS. The silica gel and organic solvents were obtained from Wako Pure Chemicals. All chemicals were persistence agricultural-chemicals analytical reagent grade.

2.3 Analysis of samples

The whole quartz fiber filters collected in Kathmandu were used for analysis. The filters collected in the other cities were cut into 60 mm ϕ for analysis. The particles on the filters were extracted with dichloromethane by the soxhlet for 24 hours. The extracts were concentrated and then diluted with n-hexane. The n-hexane

Table 2 Operational condition for HRGC/HRMS

HRGC	
Column	HP-1MS(Agilent Technology) 15 m x 0.25 mm I.D., 0.25 mm f.t.
Column temp.	70 °C (1 min. hold) - 15 °C / min. - 130 °C - 6 °C / min. - 300 °C
Carrier gas	He 1.2 mL / min.
Injection temp	300 °C
Injection mode	splitless (120 sec)
HRMS	
Ion source	EI positive
Ion source temp.	260 °C
Interface temp.	260 °C
Ionization voltage	70 eV
SIM mode	low resolution, R>1,000

solution was treated as follows [7]. The solution was cleaned up by 5 % hydrous silica gel column chromatography. The first fraction was eluted with 14 ml of n-hexane, and the second fraction was concentrated to 1 ml by the rotary evaporator, add 50 ng of fluoranthene-d₁₂ as an internal standard, and finally adjust to 1.0 ml by blowing N₂. One µL of the sample was analyzed by HRGC/HRMS. The analytical condition of HRGC/HRMS is shown in Table 2.

2.4 Compounds examined

The 65 compounds measured in this study are as follows.

2 rings : naphthalene, benzo[b]thiophene, 1-/2-methylnaphthalene, biphenyl, 2,6-/2,7-/1,3-/1,4-/2,3-/1,5-/1,2-dimethylnaphthalene, 2,3,5-trimethylnaphthalene.

3 rings : acenaphthylene, biphenylene, acenaphthene, fluorine, 9,10-dihydroanthracene, 9,10-dihydrophenanthrene, dibenzothiophene, fluorene, phenanthrene, anthracene, 1-/2-phenylnaphthalene, o-/m-/p-terphenyl, 1-/2-/3-/4-/9-methylphenanthrene, 2-/9-methylanthracene, 3,6-dimethylphenanthrene, 9,10-dimethylanthracene.

4 rings : 1,2,3,4-tetrahydrofluoranthene, 4H-cyclopenta[def]phenanthrene(4H-CdefP), fluoranthene, pyrene, benzo[b]fluoranthene(BbF), 1,1-binaphthyl, 9-phenylanthracene, benzo[a]anthracene(BaA), triphenylene,

chrysene, naphthacene,

7-methylbenz[a]anthracene(7-MeBaA).

5 rings : benzo[b]fluoranthene (BbF), benzo[j]fluoranthene (BjF), benzo[k]fluoranthene (BkF), benzo[e]pyrene (BeP), benzo[a]pyrene (BaP), perylene, 3-methylcholanthrene, 7-methyl benzo[a]pyrene (7-MeBaP), 9,10-diphenylanthracene, 1,2,3,4/1,2,5,6-dibenzanthracene.

6 rings : indeno[1,2;3-cd]pyrene (INcdP), benzo[ghi]perylene (BghiP), anthanthrene, naphtho[2,3-a]pyrene, 3,4;8,9-dibenzopyrene.

7 rings : coronene.

3. Results and Discussion

3.1 TSP(PM₁₀) Concentration and PAHs Concentration in the TSP(PM₁₀)

Table 3 shows the concentration of TSP in Ho Chi Minh, Osaka and Shijonawate and PM₁₀ in Kathmandu and PAHs concentrations of 65 compounds in the particles. The average values of PM₁₀ in Kathmandu and those of TSP in Ho Chi Minh, Osaka and Shijonawate were 0.17 ± 0.06 mg / m³, 0.10 ± 0.03 mg / m³, 0.06 ± 0.04 mg / m³, 0.08 ± 0.03 mg / m³, respectively. The concentrations of PM₁₀ in Kathmandu were very high although the particles larger than 10 µm were cut off. The average concentrations of Σ 65PAHs in Kathmandu, Ho Chi Minh, Osaka and Shijonawate were 27 ± 24 ng / m³, 11 ± 8.7 ng / m³, 22 ± 29 ng / m³, and 25 ± 41 ng / m³, respectively, and the difference between each cities are no very clear. These values are the same levels as Santiago, Chili (0.68

Table 3 Average of concentrations of SPM^a (PM₁₀^b) and PAHs compounds in Kathmandu, Ho Chi Minh, Osaka, and Shijonawate

	Kathmandu				Ho Chi Minh				Osaka				Shijonawate			
	Ave.	S.D.	Min.	Max.	Ave.	S.D.	Min.	Max.	Ave.	S.D.	Min.	Max.	Ave.	S.D.	Min.	Max.
concentration of SPM(PM ₁₀)(μg/m ³)	0.17	0.06	0.07	0.26	0.10	0.03	0.04	0.16	0.06	0.03	0.06	0.16	0.08	0.03	0.06	0.16
concentration of PAHs in air (ng/m ³)																
naphthalene	0.02	0.06	N.D.	0.21	N.D.	0.01	N.D.	0.05	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
benzo[b]thiophene	N.D. ^j	0.01	N.D.	0.02	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1-methylnaphthalene	N.D.	0.01	N.D.	0.03	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01
2-methylnaphthalene	0.01	0.02	N.D.	0.07	N.D.	N.D.	N.D.	0.02	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01
1,2-dimethylnaphthalene	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.00	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01
1,3-dimethylnaphthalene	0.01	0.01	N.D.	0.04	N.D.	N.D.	N.D.	0.02	0.03	0.01	0.02	0.04	0.03	0.01	0.01	0.06
1,4/2,3/1,5-dimethylnaphthalene	N.D.	0.01	N.D.	0.04	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01
2,6/2,7-dimethylnaphthalene	0.01	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01	0.01	N.D.	N.D.	0.01	0.01	N.D.	N.D.	0.01
2,3,5-trimethylnaphthalene	0.01	0.01	N.D.	0.02	0.01	N.D.	N.D.	0.01	0.02	N.D.	0.01	0.03	0.02	0.01	0.01	0.04
Σ 2 rings PAHs ^c	0.03	N.D.	0.03	0.03	0.02	0.02	0.01	0.12	0.06	0.01	0.04	0.09	0.07	0.03	0.04	0.14
acenaphthylene	0.01	0.01	N.D.	0.03	0.01	0.01	N.D.	0.02	0.01	0.01	N.D.	0.03	0.01	0.01	N.D.	0.04
biphenylene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
acenaphthene	0.01	0.02	N.D.	0.05	N.D.	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	0.01	0.01	N.D.	0.01	0.01
fluorene	0.01	0.02	N.D.	0.06	N.D.	N.D.	N.D.	0.01	0.02	0.01	0.01	0.04	0.02	0.01	0.02	0.05
dibenzothiophene	0.03	0.05	N.D.	0.19	0.01	N.D.	N.D.	0.02	0.03	0.02	0.01	0.07	0.04	0.03	0.01	0.09
fluorenol	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.57	0.12	0.41	0.89	0.52	0.15	0.35	0.92
o-terphenyl	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01
m-terphenyl	0.02	0.02	N.D.	0.08	N.D.	N.D.	N.D.	0.01	0.03	0.03	0.01	0.1	0.04	0.04	0.01	0.15
p-terphenyl	0.01	0.01	N.D.	0.06	N.D.	N.D.	N.D.	0.01	0.01	0.01	N.D.	0.03	0.01	0.01	N.D.	0.05
phenanthrene	0.27	0.35	0.03	1.23	0.07	0.05	0.01	0.18	0.17	0.17	0.05	0.64	0.26	0.23	0.09	0.92
1-methylphenanthrene	0.09	0.07	0.02	0.21	0.02	0.02	N.D.	0.07	0.17	0.18	0.05	0.68	0.20	0.19	0.06	0.78
2-methylanthracene	0.01	0.01	N.D.	0.02	N.D.	N.D.	N.D.	0.01	0.02	0.03	0.01	0.10	0.02	0.03	0.01	0.13
3-methylphenanthrene	0.03	0.02	0.01	0.07	0.01	0.01	N.D.	0.02	0.04	0.04	0.01	0.17	0.05	0.05	0.01	0.18
4-/9-methylphenanthrene	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	N.D.	0.02	0.03	N.D.	0.10	0.02	0.03	N.D.	0.10
3,6-dimethylphenanthrene	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	N.D.	0.03	0.03	0.01	0.11	0.03	0.03	N.D.	0.12
9,10-dihydrophenanthrene	N.D.	0.01	N.D.	0.02	N.D.	N.D.	N.D.	0.01	0.03	0.02	0.01	0.05	0.04	0.03	0.01	0.08
anthracene	0.09	0.06	0.02	0.22	0.04	0.02	0.01	0.07	0.06	0.07	0.02	0.27	0.09	0.10	0.03	0.40
2-methylphenanthrene	0.04	0.03	0.01	0.11	0.01	0.00	0.01	0.02	0.07	0.07	0.02	0.26	0.08	0.07	0.03	0.30
9-methylanthracene	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	N.D.	0.01	0.01	0.01	0.05	0.01	0.01	N.D.	0.03
9,10-dimethylanthracene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
9,10-dihydroanthracene	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01	0.01	0.01	N.D.	0.02
1-phenylnaphthalene	0.82	0.38	0.41	1.72	0.03	0.03	N.D.	0.14	0.09	0.12	N.D.	0.44	0.13	0.15	0.03	0.57
2-phenylnaphthalene	0.06	0.05	0.02	0.16	0.01	0.01	N.D.	0.03	0.05	0.06	0.01	0.22	0.07	0.08	0.02	0.32
Σ 3 rings PAHs ^d	1.5	0.93	0.60	4.0	0.22	0.11	0.07	0.44	1.4	0.97	0.73	4.2	1.6	1.2	0.86	5.2
1,2,3,4-tetrahydrofluoranthene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01
4E-CdFp	0.03	0.02	N.D.	0.06	0.01	N.D.	N.D.	0.01	0.02	0.03	N.D.	0.10	0.03	0.04	0.01	0.14
fluoranthene	0.45	0.41	0.06	1.3	0.08	0.04	0.03	0.18	0.42	0.49	0.11	1.8	0.52	0.62	0.12	2.3
pyrene	0.74	0.61	0.12	1.6	0.17	0.11	0.04	0.42	1.5	1.9	0.32	6.6	1.7	2.2	0.39	8.2
BbF	0.17	0.15	0.03	0.40	0.04	0.03	0.01	0.14	0.19	0.27	0.02	0.85	0.23	0.35	0.03	1.2
1,1-binaphthyl	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.02
9-phenylanthracene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01	0.01	N.D.	0.05	0.01	0.02	N.D.	0.09
BaA	0.88	0.91	0.07	2.9	0.1	0.09	N.D.	0.34	1.2	2	0.12	7.00	1.6	3.0	0.21	11
triphenylene/chrysenes	0.72	1.1	0.07	3.9	0.07	0.04	0.02	0.20	0.40	0.58	0.08	2.10	0.52	0.77	0.10	2.9
naphthacene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.03	0.12	0.18	0.01	0.61	0.09	0.19	N.D.	0.68
7-MeBaA	0.00	0.01	N.D.	0.02	N.D.	N.D.	N.D.	N.D.	0.02	0.03	N.D.	0.11	0.02	0.05	N.D.	0.17
Σ 4 rings PAHs ^e	3.0	2.9	0.44	9.5	0.47	0.29	0.1	1.1	3.9	5.5	0.69	19	4.6	7.2	0.88	27
BbF/BjF	2.6	2.6	0.30	9.2	0.77	0.57	0.09	2.2	0.95	1.3	0.18	4.8	1.3	2.0	0.27	7.4
BkF	2.0	2.9	0.18	10	0.44	0.39	0.05	1.5	0.98	1.2	0.21	4.6	1.3	2.0	0.29	7.3
BeP	2.9	3.0	0.41	11	1.1	0.89	0.12	3.3	1.6	1.9	0.32	7.4	2.0	3.0	0.52	11
BaP	1.3	1.2	0.11	4.0	0.28	0.28	0.03	1.0	4.0	5.9	0.57	22	4	8.9	0.52	32
Perylene	0.3	0.3	0.02	0.95	0.04	0.05	N.D.	0.15	0.65	0.98	0.09	3.5	0.58	1.3	0.07	4.7
3-methylcholanthrene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.02	0.02	0.01	0.07	0.02	0.02	N.D.	0.07
7-MeBaP	0.36	0.87	N.D.	3.1	0.03	0.04	N.D.	0.12	0.18	0.22	N.D.	0.78	0.20	0.33	0.05	1.2
9,10-diphenylanthracene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
1,2,3,4/1,2,5,6-dibenzanthracene	0.44	0.69	0.03	2.6	0.10	0.08	0.01	0.27	0.10	0.12	0.02	0.45	0.13	0.19	0.03	0.72
Σ 5 rings PAHs ^f	9.9	1.1	1.0	41	2.8	2.2	0.32	8.2	8.4	12	1.4	43	9.5	18	1.8	65
INcdP	4	3.6	0.49	13	1.8	1.5	0.21	5.3	1.9	2.4	0.37	9.1	2.3	3.7	0.56	14
BghiP	4.9	3.6	0.86	12	3.3	2.9	0.33	10	3.7	4.9	0.66	19	4.5	6.8	1.3	26
anthanthrene	0.21	0.41	N.D.	1.10	0.03	0.09	N.D.	0.41	0.95	1.6	0.10	5.8	0.87	2.1	0.07	7.5
naphtho[2,3-a]pyrene	0.20	0.31	N.D.	0.91	0.01	0.03	N.D.	0.14	0.49	0.70	0.09	2.6	0.51	1.0	0.04	3.7
3,4,8,9-dibenzopyrene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.05	0.06	0.01	0.22	0.04	0.07	0.01	0.27
Σ 6 rings PAHs ^g	9.3	7.5	1.3	26	5.2	4.4	0.54	16	7.1	9.7	1.23	36	8.2	14	2.0	51
coronene	3.2	2.5	0.84	10	2.4	1.8	0.36	6.3	0.98	1.3	0.17	5.0	1.2	1.7	0.34	6.5
Σ 7 rings PAHs ^h	3.2	2.5	0.84	10	2.4	1.8	0.36	6.3	0.98	1.3	0.17	5.0	1.2	1.7	0.34	6.5
Σ 65 PAHs ⁱ	27	24	4.4	89	11	8.7	1.5	32	22	29	4.3	108	25	41	6.4	150

^aHo Chi Minh, Osaka, and Shijonawate. ^bKathmandu. ^cSum of concentrations of 2 rings PAHs compounds. ^dSum of concentrations of 3 rings PAHs compounds. ^eSum of concentrations of 4 rings PAHs compounds. ^fSum of concentrations of 5 rings PAHs compounds. ^gSum of concentrations of 6 rings PAHs compounds. ^hConcentration of coronene. ⁱSum of concentrations of 65 kinds of PAHs shown in this table. ^jNot detected.

- 11 ng / m³, 1997)[10] and Algiers, Algeria 5.5 - 43 ng / m³, 1998)[11] and lower than Beijing, China (320 ± 430 ng / m³, 1998-2000)[6] and Chicago, USA (510 ± 470 ng / m³, 1995) [12].

3.2 Monthly Variation of the Concentrations of TSP(PM₁₀) and Σ 65PAHs

Concentrations of TSP(PM₁₀) and Σ 65PAHs in Kathmandu, Ho Chi Minh, Osaka and Shijonawate are shown in Fig 1.

Monthly Variations of the

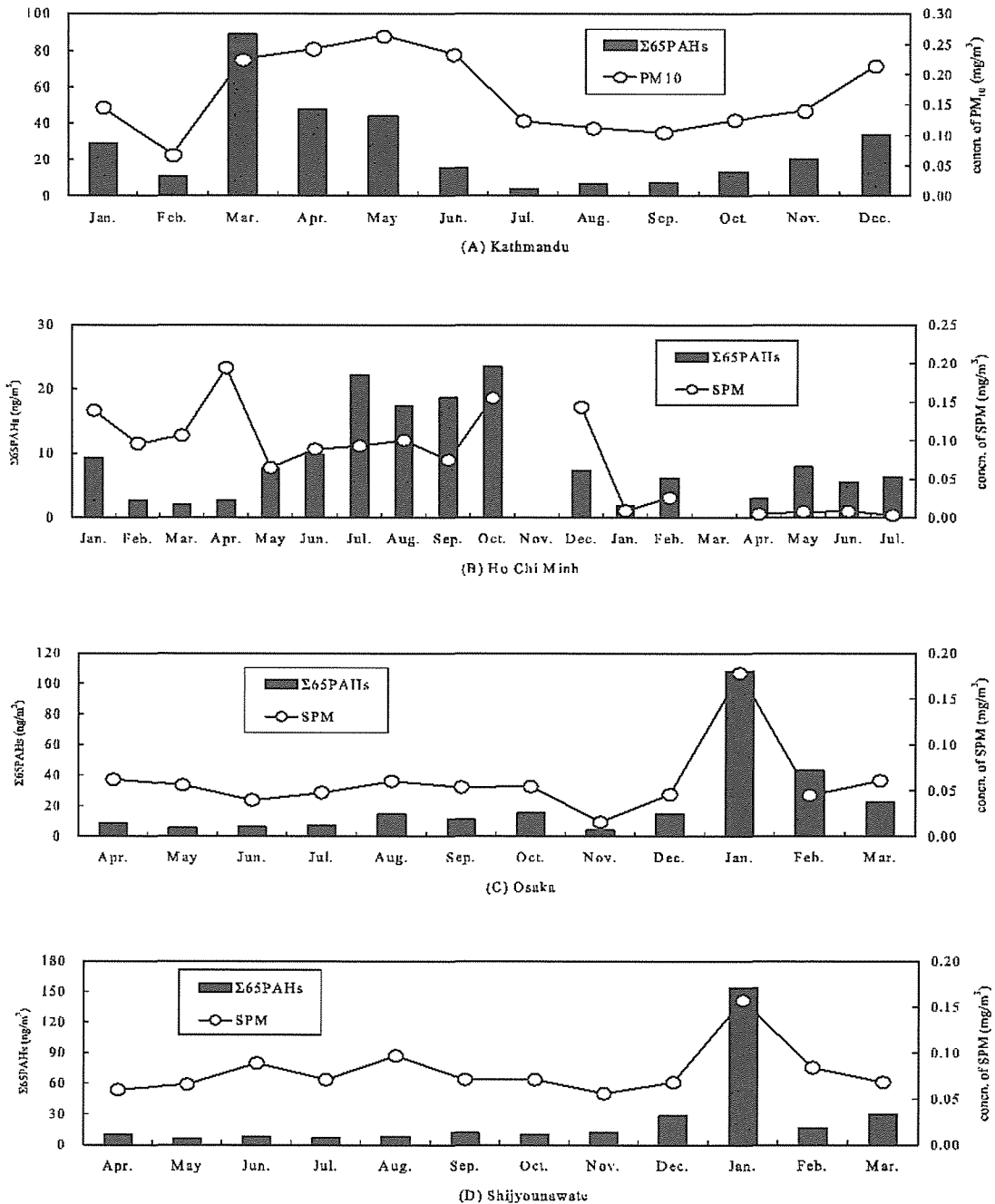


Fig.1 Monthly change in Σ 65PAHs and concentration of SPM^a (PM₁₀^b) in Kathmandu, Ho Chi Minh, Osaka and Shijonawate
^a Ho Chi Minh, Osaka, and Shijonawate. ^b Kathmandu.

The PM₁₀ and $\Sigma 65\text{PAHs}$ in Kathmandu increased from the end of summer and reached to the maximum in winter, and the maximum $\Sigma 65\text{PAHs}$ of 89 ng m⁻³ was observed in March. The concentration of PM₁₀ increases in winter because of the geographical features of Kathmandu that the stable layer of atmosphere formed in the season. Additionally, the activities of brickyards surrounding the city promoted the pollution of TSP.

In Ho Chi Minh City, $\Sigma 65\text{PAHs}$ increased, on the contrary, TSP concentrations decreased in wet season (from May to November). The $\Sigma 65\text{PAHs}$ and the TSP would not always be correlated with each other.

In Osaka and Shijonawate, the TSP and $\Sigma 65\text{PAHs}$ showed the maximum in

winter season from December to March. Especially, the peaks of $\Sigma 65\text{PAHs}$ (110 ng m⁻³ in Osaka and 150 ng m⁻³ in Shijonawate) were observed in January of 2001. On that day, the primary pollutants of NO_x also increased because of the formation of the stable layer in the atmosphere. The phenomenon has been also observed in winter in Japan as in the case of Kathmandu.

3.3. Profiles of 2 – 7 aromatic rings of PAHs

Profiles of 2 - 7 aromatic rings of PAHs in Kathmandu, Ho Chi Minh City, Osaka and Shijonawate were shown in Fig. 2. Concentrations of 2 and 3 rings of PAHs were very low. Most of them would pass through the filter and /or evaporated (sublimated) from the surface of the TSP

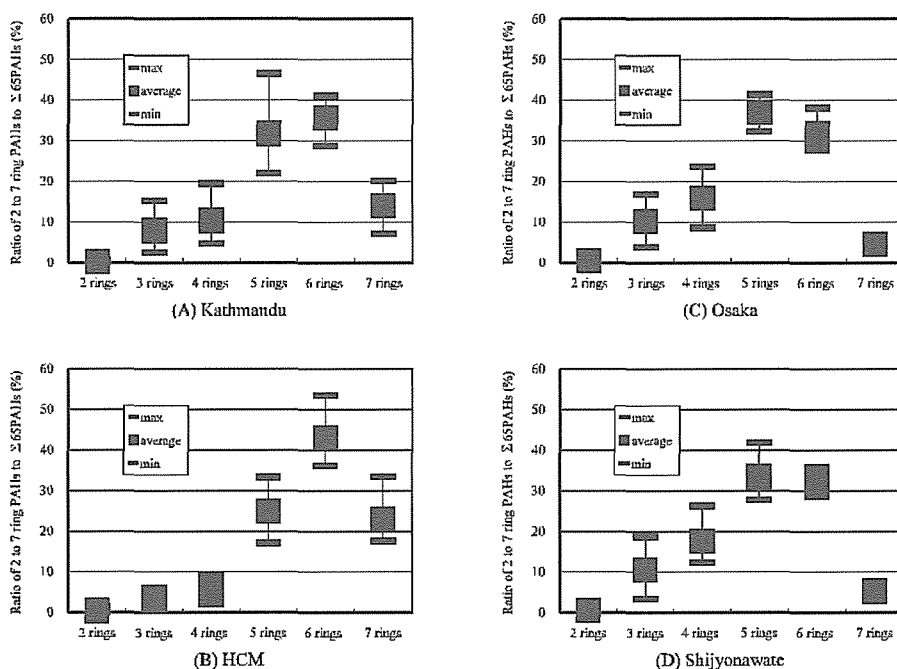


Fig.2 Profiles of 2 to 7 rings PAHs in Kathmandu, Ho Chi Minh, Osaka and Shijonawate

collected on the filters because of their high vapor pressure [13, 14]. The PAHs compounds collected on filter mainly consist of 4 - 7 rings of PAHs.

In Kathmandu, the percentages of 4, 5, 6, and 7 rings of PAHs to $\sum_{65} \text{PAHs}$ were 5-19%, 22-46%, 29-41%, and 7-20%, respectively. In Ho Chi Minh City, the percentages of 5, 6, and 7 rings of PAHs to $\sum_{65} \text{PAHs}$ were 20-33%, 37-54%, and 18-26%, respectively. The predominant categories of PAHs were the 5 and 6 rings of PAHs in both cities. In Osaka and Shijonawate, the profiles of 2 -

7 rings of PAHs showed the similar pattern with each other. The predominant categories of PAHs were 5 and 6 rings of PAHs, and the sums of them were more than 70%. The percentages of 4 rings of PAHs in summer were about 10% lower than that in winter. They would be lost on the filter while sampling in summer because of the high temperature (more than 30°C) [14]. The percentages of 7 rings of PAHs in Kathmandu and Ho Chi Minh City were about five times higher than those in Osaka and Shijonawate.

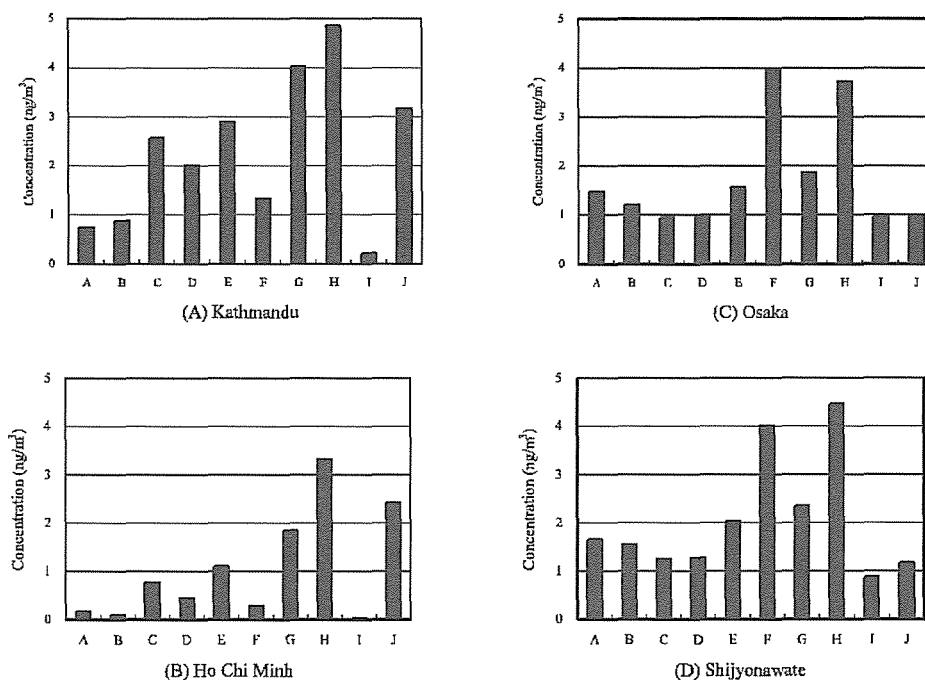


Fig.3 Averages of predominant PAHs compounds in Kathmandu, Ho Chi Minh, Osaka and Shijonawate

A:pyrene, B:BaA, C:Bb/jF, D:BkF, E:BeP, F:BaP, G:INcdP, H:BghiP, I:anthanthrene, J:coronene

3.4. Predominant components of PAHs

Average concentrations of predominant components of BghiP, INcdP,

coronene, BeP, BbF/BjF, and BkF in Kathmandu were shown in Fig. 3. These were 4.9, 4.0, 3.2, 2.9, 2.6, and 2.0 ng m⁻³,

respectively. In Ho Chi Minh City, those of predominant components of BghiP, INcdP, and coronene were 3.3, 1.9, and 2.4 ng m⁻³, respectively, and those of BeP, BbF/BjF, and BkF were in 0.46-1.1 ng m⁻³. In both cities, the high components were BghiP, INcdP, and coronene. In Osaka and Shijonawate, the predominant components were BghiP and BaP, and their average concentrations were in 4.0 ng m⁻³ level. Average concentrations of BaP in Osaka and Shijonawate were as in same tolerable level as in 5 ng m⁻³ provided in the Dutch

guidelines [15] [(Slooff et al., 1989), but about 3 times higher than that of Kathmandu and about ten times higher than that of Ho Chi Minh City. In four cities, the highest component was a BghiP and the concentration was in the range of 3.3 - 4.9 ng m⁻³.

3.5. Estimation of emission sources of PAHs

Zakaria et al. [16] reported that the origin of PAHs could be estimated from the ratio (Σ MPs/P) of sum of concentrations of

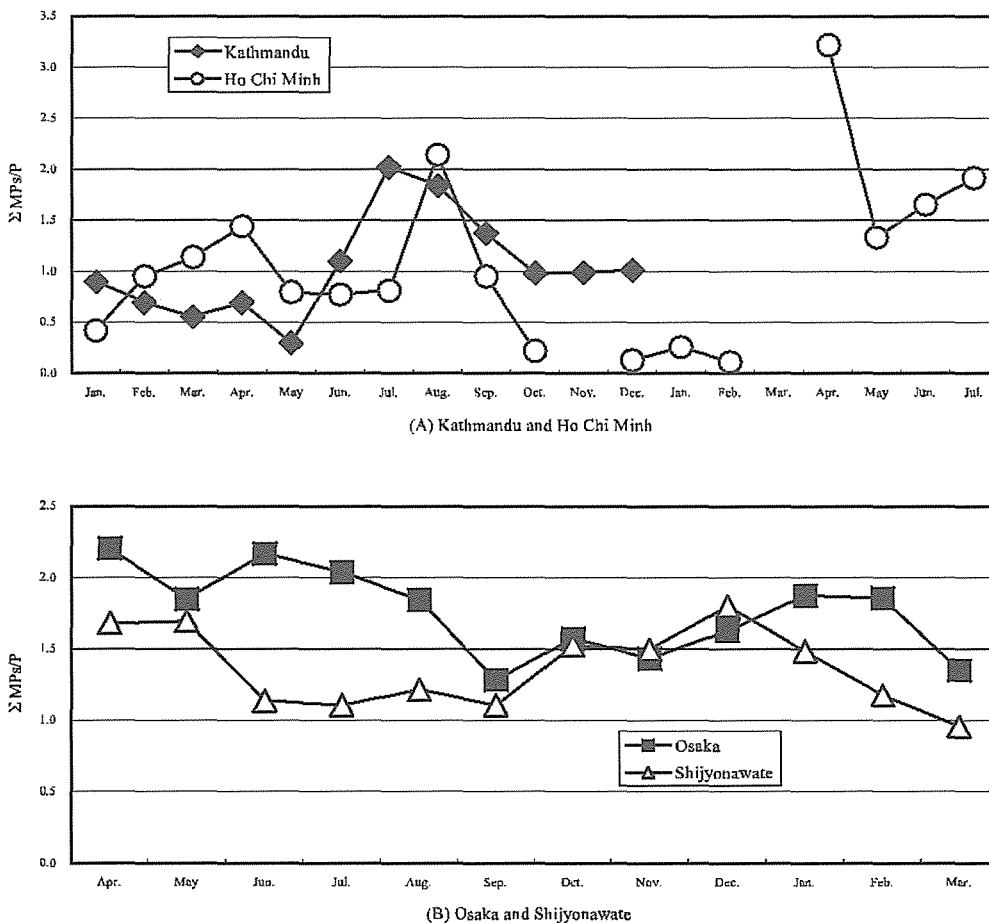


Fig.4 Monthly changes in Σ MPs/P in Kathmandu, Ho Chi Mihn, Osaka and Shijyonawate

methylphenanthrene isomers (Σ MPs/P) to that of phenanthrene (P). These ratios in the petrol (petrogenic origin) were more than 2.0, whereas those of exhaust from the combustion process of the materials (pyrogenic origin) were less than 1.0. The Σ MPs/P was calculated in each city, and the results were shown in Fig.4. Averages of Σ MPs/P in Kathmandu, Ho Chi Minh City, Osaka, and Shijonawate were 1.04 ± 0.50 , 1.05 ± 0.50 , 1.76 ± 0.31 , and 1.37 ± 0.28 , respectively. According to the criteria of the Σ MPs/P, the pollutions of particulate PAHs in

Kathmandu and Ho Chi Minh City would be mainly originated from the pyrogenic sources such as the combustion of fossil fuels from automobiles. In Osaka and Shijonawate, they would be originated from both of petrogenic and pyrogenic sources.

Grimmer et al. [17] had estimated the emission sources of PAHs caused by the pyrogenic origin (pyrogenic-PAHs) on the basis of the ratio of INcdP to sum of INcdP and BghiP. The ratios (INcdP/(INcdP + BghiP)) of 0.18, 0.33, and 0.5 were corresponding to the exhaust gases of gasoline and diesel engines, and of

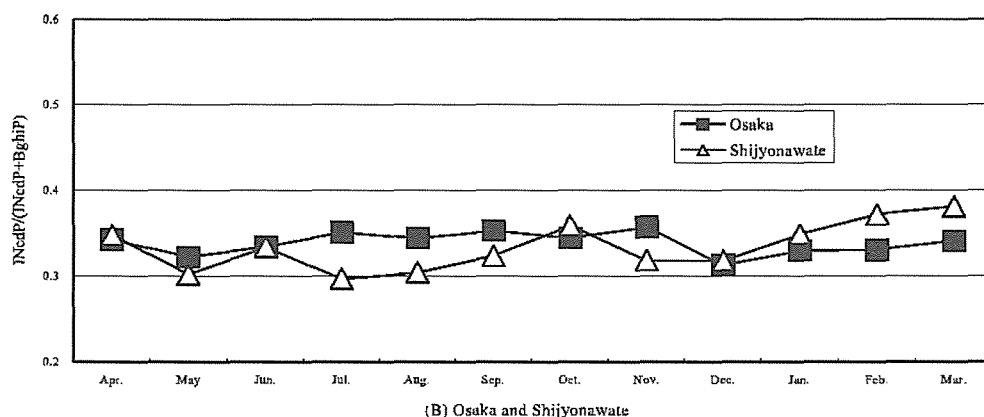
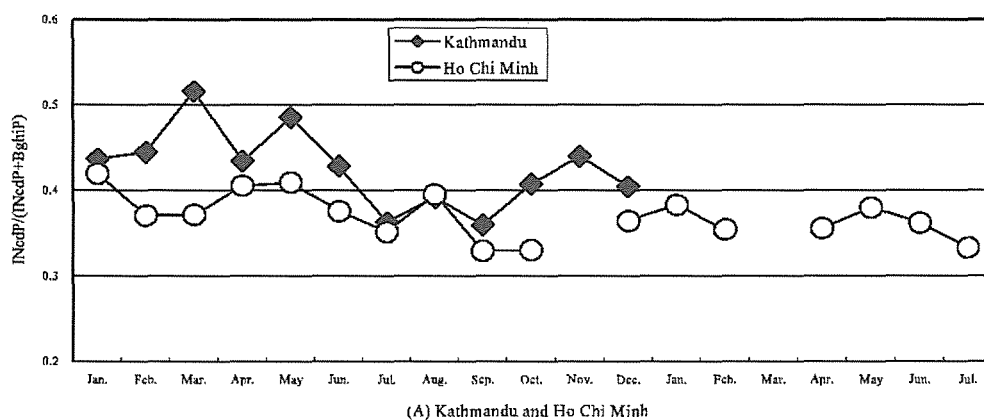


Fig.5 Monthly changes in INcdP/(INcdP+BghiP) in Kathmandu, Ho Chi Minh, Osaka and Shijonawate

combustion of the coal, respectively. Monthly variations of the INcdP/(INcdP+BghiP) in the four cities were shown in Fig. 4. An average of the INcdP/(INcdP+BghiP) in Kathmandu was 0.43 ± 0.05 . This value was close to that of the combustion of coal. The ratios increased and reached to the maximum (0.48) in March. During the winter season, the production of brickyards around the city became active, and accelerated the pollution from the exhaust of combustion of coal in the atmosphere. In summer (from July to September), the average of the ratios was 0.37 and close to the value (0.33) of the exhaust gases of the diesel engines. Averages of the INcdP/(INcdP+BghiP) in Ho Chi Minh City, Osaka, and Shijonawate were 0.37 ± 0.03 , 0.34 ± 0.01 , and 0.33 ± 0.03 , respectively. These values were close to that of the exhaust gases of the diesel engines.

4. Conclusion

A Survey on particulate PAHs was conducted in Asian Cities, Kathmandu, Ho Chi Minh City, Osaka, and Shijonawate for one year from 2001 to 2004. An average of PM_{10} in Kathmandu was 0.17 ± 0.06 mg m^{-3} , and averages of TSP of Ho Chi Minh City, Osaka, and Shijonawate were 0.11 ± 0.04 mg m^{-3} , 0.06 ± 0.03 mg m^{-3} , and 0.08 ± 0.03 mg m^{-3} , respectively. Averages of $\sum 65PAHs$ in Kathmandu, Ho Chi Minh City, Osaka, and Shijonawate were 27 ± 24 ng m^{-3} , 11 ± 7.9 ng m^{-3} , 22 ± 29 ng m^{-3} , and 25 ± 41 ng m^{-3} , respectively. From the estimation of specific

components of PAHs, the pollutions of particulate PAHs were originated from the pyrogenic sources in Kathmandu and Ho Chi Minh City, and those from both of petrogenic and pyrogenic ones in Osaka and Shijonawate. Among pyrogenic sources, the exhaust gases from the diesel engines mainly contributed to the pollution of PAHs in Asian cities, but in Kathmandu the contribution of the exhaust from the combustion of coal increased in winter because of the activities of brickyards.

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