

PAHs and Aerosol Carbons in the Exhaust of a Gasoline Powered Engine

Shui-Jen Chen *, Wei-Jain Jian, Yi-Chu Huang

Department of Environmental Science and Engineering, National Pingtung University of Science and Technology, NeiPu, 91207, Pingtung, Taiwan, ROC

Chu-Chin Hsieh

Department of Environmental and Safety Engineering, National Yunlin University of Science and Technology

Meei-Fang Shue and Bai-Luh Wei

Department of Environmental Engineering and Health, Tajen Institute of Technology

A Mazda E5 gasoline – powered engine operated on a dynamometer was used to investigate the PAH (Polycyclic Aromatic Hydrocarbons) and carbon emission. A 92-leadfree gasoline (92-LFG), a 95-leadfree gasoline (95-LFG) and a premium leaded gasoline (PLG) were used as tested fuels. Twenty one individual PAHs were analyzed by a gas chromatography /mass spectrometer (GC/MS), while the carbon composition of the aerosol samples were determined by an elemental analyzer. This study showed that the total – PAH concentration in the exhaust of 95- LFG was 1.29 and 1.33 times of magnitude higher than those of PLG and 92-LFG. With or without a catalyst converter system, the PAHs from primary sources mainly existed in the gas phase. Vehicles with a catalyst converter could reduce PAHs emission by more than 90%. In addition, it could reduce carbonaceous emission by more than 50% for total carbon (TC), 40% for elemental carbon (EC) and 60% for organic carbon (OC), respectively. The OC/EC ratios were all greater than 1.0 for carbonaceous aerosols originated from the gasoline powered engine.

Keywords: PAHs; elemental carbon; organic carbon; exhaust

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are major semi-volatile organic compounds (SOCs) found simultaneously in the gas phase and on airborne particulate emitted mostly from anthropogenic activities, especially motor vehicles including gasoline-engine and diesel-engine automobiles [Bjorseth and Ramdahl (1985); Lee

et al. (1995)]. The values of total- PAH (sum of 21 individual PAHs) composition in the fine particles ($D_p < 1.0 \mu\text{m}$) for bus-station atmosphere was in average about 2.2 and 9 times higher than that measured in an urban and rural atmosphere, respectively [Chen et al. (1997)]. Traffic was suggested to be the major source for both concentrations of PAHs and genotoxic activity in urban air [Henderson et al. (1984); Pyysalo et al. (1987) and Tuominen et al. (1988)]. Some of PAHs and their derivatives are potential mutagens and carcinogens and are probably the major culprits in causing high lung cancer rate [Doll and Peto (1981), Speizer (1986),

*Corresponding author:

Tel.: +886-8-7740263

Fax: +886-8-7740364

E-mail address: chensj@mail.npust.edu.tw

Westerholm et al. (1988) and Mi et al. (1998)].

Carbonaceous aerosols in urban areas are directly emitted from stationary and mobile sources. Usually, carbonaceous aerosol constituents are classified into organic carbon (OC), elemental carbon (EC), and carbonate (CO_3^{2-}) [Wolff (1968)]. The OC contributes to visibility reduction and may contain carcinogenic compounds detrimental to human health. The EC, or black carbon, has a significant impact on reducing visibility because of its light absorption properties in the atmosphere. In addition, EC is also a potential transporter of toxic compounds into human and animal respiratory systems [Novakov (1984) and Japar et al. (1986)]. Because the contribution of carbonate carbon to total carbon (TC) is less than 5%, carbonaceous aerosols are mainly comprised of OC and EC [Japar et al. (1986)]. The dominant source of EC is diesel emission [Cadle and Mulawa (1990)]. EC is produced only in combustion processes and is a primary pollutant. In contrast to EC, OC is not only directly emitted from sources, but also can be produced by atmospheric reactions from gaseous precursors.

Information about the characteristics of PAHs in Taiwan's urban air is especially important because Taiwan is a traffic congested and densely populated area. The average vehicle density is 475 vehicle/km² in Taiwan, which is the highest one in the world. For their possible carcinogenicity and mutagenicity, PAHs in Taiwan's ambient air have been investigated extensively in recent years [Lee et al. (1995) and Chen et al. (1997)]. As a matter of fact, the emission of PAHs from the gasoline-powered engines is influenced by many operation factors. External factors of engines included the effect of fuel, lubricant and automotive fuel additives [Handa et al. (1979), Pedersen et al. (1980), Westerholm et al. (1988), Wallington et al. (1993) and Mi (1996)]. The content of aromatic in fuel was

found to influence particle-bound PAH emission almost linearly. The lubricant influenced particle-bounded PAH emissions mainly because of its PAH content and consumption rate. The lubricant PAH content was found to increase linearly with time of use, while, the unused lubricant was found to contain almost no PAH [Pedersen et al. (1980)]. Westerholm et al. also analyzed the engine lubricating oil and showed that no significant increase of PAH occurred during the experiment [Westerholm et al. (1988)]. They also found that the total-PAH (sum of 14 PAHs) contents in the lubricating oil before and after testing were both well below 0.4 ppm [Westerholm et al. (1988)].

The main objectives of this study were to investigate the concentrations and emission characteristics of 21 individual PAHs in the exhaust of a 92-leadfree gasoline (92-LFG), a 95-leadfree gasoline (95-LFG) and a premium leaded gasoline (PLG) powered-engine installed on a dynamometer. The rotary speeds were separately set to 1,000, 1,500, 2,200 and 3,000 rpm to simulate the idling condition and the cruising speeds at 40, 80 and 110 km/h, respectively [Mi et al. (1998)]. In addition, the effect of a catalyst converter on PAH emission was investigated and compared. Carbonaceous aerosols are also important owing to the health effects caused by carcinogenic activity. Therefore, carbonaceous aerosols were also discussed in this study.

2. Experimental Section

2.1 Vehicle Engine and Dynamometer System

The gasoline-powered engine used in this study was a Mazda E5 described in a previous work [Mi et al. (1998)]. The engine was installed and operated on a dynamometer (Model FE

60-100-150S) manufactured by Borghi & Saveri Corp. With recharging a new gasoline, the system (including gas tank, fuel filling system, cylinder, and the manifold of inlet air and exhaust) was first cleaned, followed by a dirty procedure (that is, a sequence of 15 minutes engine running and 45 minutes stop, then repeated 10 times). Prior to each set of experiment, both the lubricating oil and oil filter were changed. The engine speeds were separately set to 1,000, 1,500, 2,200 and 3,000 rpm to simulate the idling condition and cruising speeds at 40, 80 and 110 km/h, respectively [Mi et al. (1998)]. In this study, three repeated runs of experiment were performed under each of the prescribed conditions.

2.2 Gasoline Fuels

In this study, three commercial fuels made by China Petroleum Corp.— 92-LFG, 95-LFG and PLG were used as test fuels for the gasoline engine. The specifications of these three gasolines are shown in Table 1 [Mi (1998)].

2.3 Sampling System for Engine Exhaust

After draft design, the PAH sampling system (PSS) for engine exhaust was manufactured by Bectech Group Ltd. Co., Taipei, Taiwan. A schematic diagram of the sampling system is shown in Figure 1. To ensure the quality of the sampling system, the isokinetic sampling is adopted on the sampling procedure. Particulate-phase and gas-phase PAHs samples were respectively collected, using a sampling system from the tailpipe exhaust of gasoline powered engines, on a quartz fiber filter and a glass cartridge containing PUF plug followed by XAD-2 resin and finally a PUF plug [Mi et al. (1998)]. The quartz fiber filters (Tissuquartz 2500QAT-UP) produced by Pallflex Company

Table 1. The specifications of motor gasolines for 92-PLG, 95-LFG and PLG

Specification	92-LFG	95-LFG	PLG
Products No.	113-F12092	113-F12095	113-F11095
Octane No.	92	95	95
Reid Vapor Pressure kPa at 37.8°F	69	69	69
Sulfur Content, wt%	0.10	0.10	0.10
Lead Content, g Pb/L	0.013	0.013	0.08
Distillation, °C			
10%	74	74	74
50%	127	127	127
90%	190	190	190
End Point, °C	225	225	225
Residue, vol%	2	2	2
Color	Blue	Red	Yellow

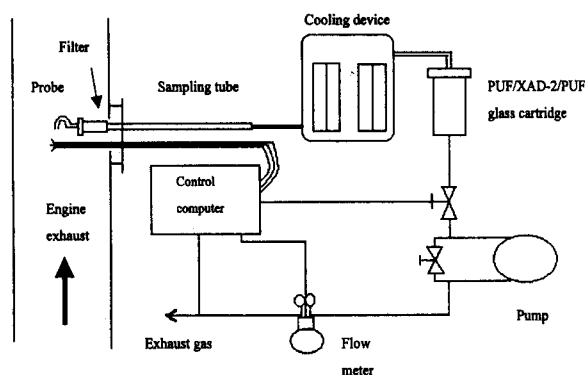


Figure 1. A schematic diagram of the sampling system.

(Putran, CT, U.S.A) were cleaned with distilled-deionized water and n-hexane, then placed in an oven at 900°C for 1.5 hr to reduce their carbon blank. Thus, the background concentration in the quartz fiber filter and matrix, which can influence the analyzer results, can be minimized [Chen et al. (1997)]. Under the same experimental condition, three repeated samples were collected and analyzed.

3. PAH Analysis

After final weighing (if needed), each PAH-containing sample including glass cartridges and the quartz fiber filters were Soxhlet extracted with a mixed solvent (n-hexane and dichloromethane, v:v = 1:1) for 24 h separately. The extract was then concentrated, cleaned up, and reconcentrated to 0.5 mL with ultra pure nitrogen [Chen et al. (1997) and Mi et

Table 2. PAH concentration in 92-LFG, 95-LFG and PLG.

PAHs	Concentration					
	92-LFG		95-LFG		PLG	
	Range (mg/L)	Mean (mg/L)	Range (mg/L)	Mean (mg/L)	Range (mg/L)	Mean (mg/L)
Nap	3.14~7.84	5.71± 0.08	5.31~10.8	8.23± 1.62	62.4~89.2	78.1± 13.6
AcPy	0.56~1.12	0.87± 0.31	1.12~1.34	1.22± 0.12	0.80~1.12	0.94± 0.13
Acp	0.09~0.28	0.20± 0.08	0.12~0.33	0.28± 0.16	0.03~0.15	0.08± 0.04
Flu	0.80~1.22	0.97± 0.28	0.61~1.22	0.71± 0.21	0.06~0.33	0.15± 0.05
Ant	0.41~0.97	0.57± 0.14	0.08~0.18	0.13± 0.03	0.01~0.28	0.14± 0.06
PA	0.15~0.44	0.25± 0.09	0.18~1.17	0.41± 0.19	0.02~0.13	0.06± 0.02
FL	0.04~0.09	0.06± 0.01	0.06~0.12	0.09± 0.03	0.01~0.09	0.06± 0.02
Pyr	0.02~0.11	0.06± 0.02	0.02~0.41	0.06± 0.02	0.01~0.04	0.02± 0.01
CYC	0.01~0.04	0.02± 0.01	N.D.~0.05	0.02± 0.01	N.D.~0.02	0.01± 0.004
BaA	N.D.~0.01	0.004± 0.002	0.01~0.09	0.06± 0.02	N.D.~0.03	0.02± 0.013
CHR	0.004~0.01	0.003± 0.001	0.01~0.06	0.04± 0.01	0.01~0.02	0.01± 0.004
BbF	N.D.~0.02	0.01± 0.004	0.01~0.04	0.03± 0.01	0.01~0.03	0.01± 0.008
BkF	N.D.~0.01	0.004± 0.002	N.D.~0.01	0.007± 0.004	N.D.~0.01	0.004± 0.002
BaP	N.D.~0.01	0.006± 0.003	N.D.~0.01	0.006± 0.005	N.D.~0.005	0.002± 0.001
BeP	0.002~0.01	0.006± 0.002	N.D.~0.03	0.01± 0.004	N.D.~0.009	0.005± 0.003
PER	N.D.~0.02	0.01± 0.004	0.01~0.02	0.02± 0.013	N.D.~0.06	0.04± 0.01
IND	N.D.~0.05	0.03± 0.013	N.D.~0.08	0.05± 0.02	0.06~0.26	0.13± 0.04
DBA	N.D.~0.09	0.03± 0.021	N.D.~0.18	0.04± 0.021	0.01~0.02	0.01± 0.008
BbC	0.01~0.08	0.04± 0.013	0.01~0.38	0.21± 0.09	N.D.~0.08	0.04± 0.02
BghiP	N.D.~0.07	0.03± 0.019	N.D.~0.41	0.12± 0.07	0.01~0.40	0.12± 0.09
COR	N.D.~0.02	0.01± 0.007	N.D.~0.05	0.02± 0.01	N.D.~0.08	0.04± 0.03
Total-PAHs	5.24~12.5	8.89± 1.04	7.55~17.0	11.8± 2.15	64.3~92.4	80.0± 11.3

N.D. : Not Detectable.

al. (1998)]. A gas chromatograph (GC) (Hewlett-Packard 5890A) with a mass selective detector (MSD) (Hewlett-Packard 5972) and a computer workstation was used for the PAH analysis.

Analysis parameter and procedure of GC/MS were similar to those described in previous paper [Chen et al. (1997)].

The concentrations of the following PAHs were determined: Naphthalene (Nap), Acenaphthylene (AcPy), Acenaphthene (Acp), Fluorene (Flu), Phenanthrene (PA), Anthracene(Ant), Fluoranthene (FL), Pyrene (Pyr), Cyclopenta(c,d)pyrene (CYC), Benz(a)anthracene (BaA), Chrysene (CHR), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), Benzo(e)pyrene (BeP), Benzo(a)pyrene (BaP), Perylene (PER), Indeno(1,2,3,-cd)pyrene (IND), Dibenz(a,h)-

anthracene (DBA), Benzo(b)chrysene (BbC), Benzo(ghi)perylene (BghiP), and Coronene (COR). This study showed the recovery efficiency of PAHs varied between 0.83 and 1.12, averaging 90%. Analysis of field blanks, including filters and cartridge, found no significant contamination (GC/MS integrated area < detection limit).

4. Carbon Analysis

An elemental analyzer (W.C. Heraeus Elemental Analyzer CHN-O-Rapid) was used to analyze the carbon composition of aerosol samples. The Thermal Conductivity Detector (TCD) was used to detect the CO₂ content in the aerosol samples after the thermal process. The operation condition was: oxidation tube temperature 900°C; reduction tube temperature

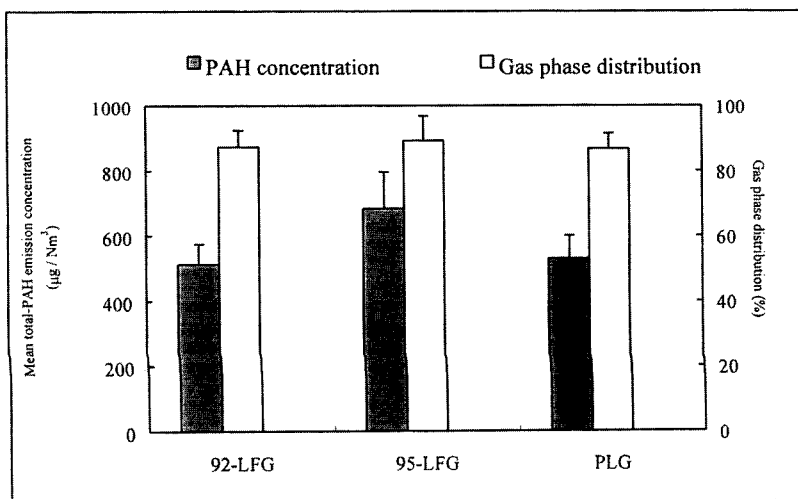


Figure 2. PAH emission concentration and phase distribution from the 92-LFG, 95-LFG and PLG powered engine without a catalyst converter.

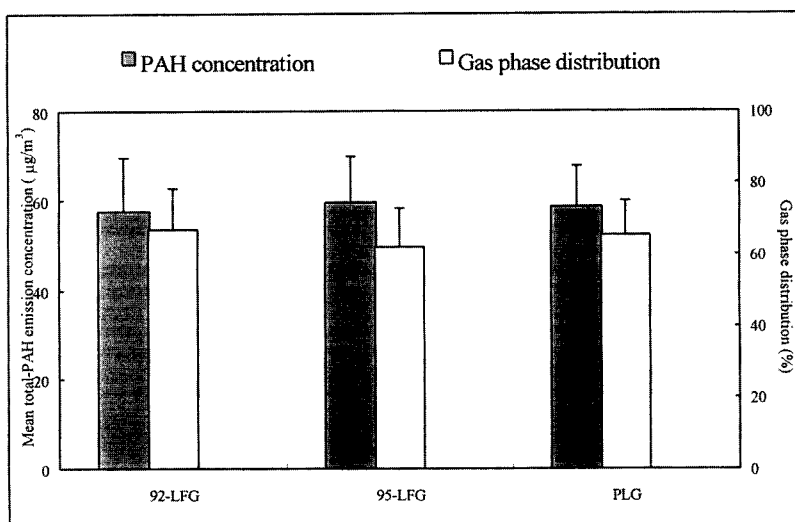


Figure 3. PAH emission concentration and phase distribution from the 92-LFG, 95-LFG and PLG powered engine with a catalyst converter.

600°C; heating time 15 min. One quarter of the sampled quartz fiber filter was divided into two parts and their weights were measured. One part of the quartz fiber filter was analyzed for the carbon content without any pretreatment. The carbon obtained here was the TC. Another part of the quartz fiber filter was put into the 340°C oven, and heated for 10 min to remove OC [Cadle and Groblicki (1982); Chen et al. (1997)]. By applying the same method used before, the EC can be obtained. OC can be obtained by subtracting EC from the TC.

5. Results and Discussion

5.1 PAH Content in the Gasoline Fuel

Twenty one individual PAH concentration in 92-LFG, 95-LFG and PLG are shown in Table 2. The total-PAH concentration was between 5.24 and 12.5 mg/L for 92-LFG, between 7.55 and 17.0 mg/L for 95-LFG and between 64.3 and 92.4 mg/L for PLG, respectively. The mean total-PAH concentration of PLG was 80 mg/L. This mean value was approximately 9.0 and 6.8 higher than those mean values for 92-LFG and

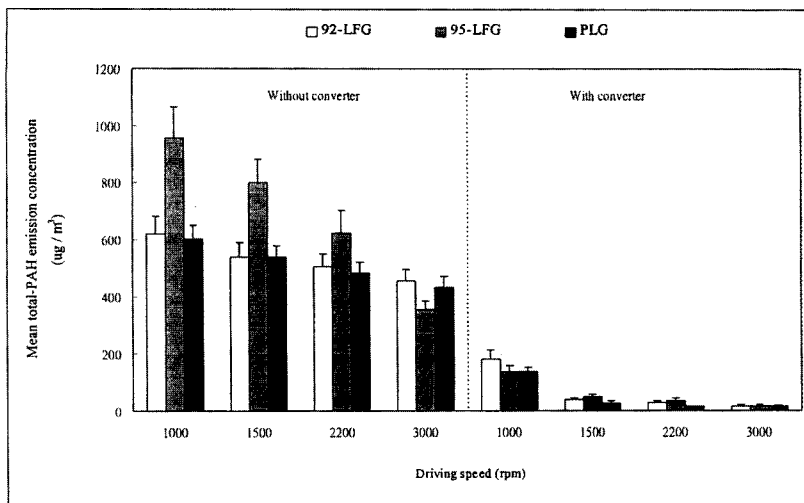


Figure 4. PAH emission concentration from the 92-LFG, 95-LFG and PLG powered engine at various driving speeds.

95-LFG, respectively. The worldwide trend to cut down the addition of lead into gasoline increases the content of PAHs in the atmosphere in order to maintain the knock resistance of the fuel [Pedersen et al. (1980)]. In 92-LFG, the mean PAH concentrations higher than 0.1 mg/L, in sequence, are 5.71 mg/L for Nap, 0.97 mg/L for Flu, 0.87 mg/L for AcPy, 0.57 mg/L for Ant, 0.25 mg/L for PA and 0.20 mg/L for Acp, while those in 95-LFG, in sequence, are 8.23 mg/L for Nap, 1.22 mg/L for AcPy, 0.71 mg/L for Flu, 0.41 mg/L for PA, 0.28 mg/L for Acp, 0.13 mg/L for Ant and 0.12 mg/L for BghiP. However, in PLG, the mean PAH concentrations higher than 0.1 mg/L, in sequence, are 78.1 mg/L for Nap, 0.94 mg/L for AcPy, 0.15 mg/L for Flu, 0.14 mg/L for Ant, 0.13 for IND and 0.12 mg/L for BghiP. In these three gasolines, Nap has the highest concentration. Of the total PAH concentration, 64.2% for 92-LFG, 69.7% for 95-LFG and 97.6% for PLG were contributed by Nap.

5.2 PAH Concentration and Phase Distribution in the Engine Exhaust

Without a catalyst converter, the measured total-PAH concentration (gas+particle phases) for

95-LFG powered engine at four different cruising speeds ranged between 356 and 957 $\mu\text{g}/\text{Nm}^3$ and averaged 684 $\mu\text{g}/\text{Nm}^3$ (Figure 2). The mean total-PAH concentration of 95-LFG was approximately 33% and 29% higher than those of 92-LFG and PLG, respectively. The gas phase distribution of total-PAHs in 92-LFG powered engine was between 85.1 and 89.1%, while those were between 76.6 and 92.7% and between 84.5 and 90.3% for the 95-LFG and PLG powered engine, respectively (Figure 2). Because the PAHs in the exhaust stream were at a high temperature, over 86% of mean total-PAH mass was in the gas phase (Figure 2).

However, the measured total-PAH concentration (gas+particle phases) at four different cruising speeds were 57.6, 59.5 and 58.5 $\mu\text{g}/\text{Nm}^3$ for 92-LFG, 95-LFG and PLG powered engine with catalyst converter, respectively (Figure 3). The results showed that vehicles with catalyst converters could reduce PAHs emission by more than 90%. With catalyst converter, more than 62% of mean total-PAH mass existed in the gas phase (Figure 3). Whether a catalyst converter was adopted or not, it is apparent that PAHs from the primary sources mainly existed in the gas phase for both cases.

Table 3. The fraction of PAH-homologue from a gasoline- powered engine.

PAH Homologue	The Fraction of PAH Homologue (%)							
	Without Catalyst Converter				With Catalyst Converter			
	92-LFG	95-LFG	PLG	Mean	92-LFG	95-LFG	PLG	Mean
2-ring	52.9	64.2	58.5	58.5 ± 4.2	54.3	58.6	49.8	52.9 ± 5.3
3-ring	34.8	20.2	19.7	24.9 ± 3.1	36.9	27.7	37.8	34.1 ± 2.9
4-ring	4.30	3.40	2.35	3.35 ± 0.4	7.22	4.63	5.41	5.75 ± 0.5
5-ring	4.20	10.3	17.4	10.6 ± 1.2	3.48	7.21	3.45	4.71 ± 0.5
6-ring	2.70	1.20	1.20	1.70 ± 0.12	1.21	1.24	2.89	1.78 ± 0.14
7-ring	1.10	0.70	0.50	0.77 ± 0.09	0.89	0.62	0.65	0.72 ± 0.08

Table 4. Concentration and particle-bound composition of TC, EC and OC from 92-LFG, 95-LFG and PLG powered engine without a catalyst converter.

Items	Carbonaceous Constituents	92-LFG			95-LFG			PLG		
		Range ^a	Mean	RSD (%)	Range ^a	Mean	RSD (%)	Range ^a	Mean	RSD (%)
TC	Concentration(mg/Nm ³)	2.05~11.5	6.82	10.1	2.19~8.87	6.11	9.7	2.02~11.6	7.01	12.1
	Composition(g/g)	0.365~0.821	0.627	11.2	0.453~0.950	0.764	11.6	0.289~0.803	0.659	8.9
EC	Concentration(mg/Nm ³)	0.894~4.42	2.81	7.9	0.19~3.23	1.72	8.9	0.826~4.12	2.14	9.7
	Composition(g/g)	0.101~0.401	0.280	10.3	0.082~0.281	0.190	12.1	0.059~0.329	0.218	10.6
OC	Concentration(mg/Nm ³)	0.189~8.22	4.01	11.5	0.284~6.82	4.39	10.7	0.444~10.2	4.87	12.3
	Composition(g/g)	0.037~0.484	0.347	10.8	0.123~0.766	0.574	8.3	0.148~0.706	0.441	9.6

a: The rotary speeds were set at four different cruising speeds (i.e. 1000, 1500, 2200 and 3000rpm) to simulate the idling condition and the cruising speeds at 40km/h, 80km/h and 110km/h, respectively.

The results showed that PAH concentration in the exhaust of automobile engine was affected by the driving speed (Figure 4). For 92-LFG, 95-LFG and PLG powered engines without a catalyst converter, the highest total-PAH concentration was observed at driving speeds of 1,000 rpm (i.e. idling condition), while the lowest total-PAH concentration was found at 3,000 rpm (i.e. 110 km/h), respectively. Whether a catalyst converter was adopted or not, the total-PAH

DBA and BbC for the 5-ring, IND and BghiP for the 6-ring and COR for the 7-ring. Without a catalyst converter, the mean F% of PAH homologue higher than 5%, in sequence, were 58.5% for 2-ring, 19.7% for 3-ring and 17.4% for 5-ring, while those were 2.35%, 1.2% and 0.77% for 4-, 6- and 7-ring PAH homologue, respectively. However, with a catalyst converter, the mean F% of PAH homologue higher than 5%, in sequence, were 52.9% for 2-ring, 34.1% for

4.87 mg/Nm³ for PLG, respectively (Table 4). These mean values of EC and OC were 70 and 400 times higher than those measured in traffic intersection and rural atmosphere, respectively [Chen et al. (1997)]. These carbonaceous constituents emitted from the mobile exhaust would be reduced by photolysis, evaporation, or reaction with other components during the dispersion and transport processes.

The TC, EC and OC mass adsorbed on the air particulates and normalized by the particle mass is called particle-bound composition of TC, EC and OC (g/g). The mean particle-bound compositions of TC, EC and OC emitted from gasoline powered engine were 0.627, 0.280 and 0.347 g/g for 92-LFG, 0.764, 0.190 and 0.574 g/g for 95-LFG and 0.659, 0.218 and 0.441 g/g for PLG, respectively (Table 4). The mean particle-bound composition of TC showed that carbonaceous aerosols accounted for 62.7%~76.4% of total suspended particulate (TSP) mass loadings. They were the most abundant components of aerosols from vehicle exhausts. These TC compositions were approximately 3 times higher than both those measured in traffic intersection and rural atmosphere [Chen et al. (1997)].

After adopting a catalyst converter, the mean concentrations of TC, EC and OC emitted from the gasoline powered engine were 2.93, 1.10 and 1.83 mg/Nm³ for 92-LFG, 3.30, 1.50 and 1.80 mg/Nm³ for 95-LFG and 3.37, 1.48 and 1.85 mg/Nm³ for PLG, respectively (Table 5). The mean particle-bound compositions of TC, EC and OC emitted from gasoline powered engine were 0.354, 0.156 and 0.198 g/g for 92-LFG, 0.329, 0.172 and 0.157 g/g for 95-LFG and 0.361, 0.188 and 0.173 g/g for PLG, respectively (Table 5). The results showed that, in addition to PAHs, vehicles with catalyst converters could reduce 40% for EC and 60% for OC, respectively. The

carbonaceous constituents decreased significantly with adoption of a catalyst converter.

5.5 The Concentration Ratios of OC/TC and OC/EC in the Engine Exhaust

The concentration ratios of OC/TC and OC/EC for carbonaceous aerosols measured from the engine exhaust are shown in Table 6. Without a catalyst converter, the mean OC/TC ratios in the engine exhaust were 0.59, 0.72 and 0.69 for 92-LFG, 95-LFG and PLG, respectively. After adopting a catalyst converter, the mean OC/TC ratios were 0.62, 0.54 and 0.55 for 92-LFG, 95-LFG and PLG, respectively. Because more OC originated from the vehicle emission, the average OC/TC ratio for carbonaceous aerosols emitted from these gasoline powered engine were approximately 10% and 44% higher than those measured in the traffic intersection and rural atmosphere, respectively [Chen et al (1997)].

The mean OC/EC ratios in the engine exhaust were 1.43, 2.55 and 2.28 for 92-LFG, 95-LFG and PLG, respectively. After adopting a catalyst converter, the mean OC/EC values were 1.66, 1.20 and 1.25 for 92-LFG, 95-LFG and PLG, respectively. EC is an inert material and will not be influenced by the atmospheric environment. The results from the study of Nunes et al. indicate that EC is produced only in the combustion process and is a primary pollutant [Nunes and Pio (1993)]. In contrast to EC, during long-range transport, the organic constituents of the aerosol are probably depleted quickly by photolysis and evaporation processes, while EC is transported efficiently [Nunes and Pio (1993)]. In this study, the OC/EC ratios were greater than 1.0 for carbonaceous aerosols originating from the gasoline powered engine, while those measured in the rural area reported in a previous study [Chen et al. (1997)] were all less than 0.65. The

Table 5. Concentration and particle-bound composition of TC, EC and OC from 92- LFG, 95-LFG and PLG powered engine with a catalyst converter.

Items	Carbonaceous Constituents	92-LFG			95-LFG			PLG		
		Range ^a	Mean	RSD (%)	Range ^a	Mean	RSD (%)	Range ^a	Mean	RSD (%)
TC	Concentration(mg/Nm ³)	1.00~6.43	2.93	9.3	1.08~6.33	3.30	7.9	1.16~6.55	3.37	7.8
	Composition(g/g)	0.177~0.550	0.354	11.6	0.197~0.553	0.329	10.3	0.201~0.564	0.361	14.2
EC	Concentration(mg/Nm ³)	0.415~1.97	1.10	13.1	0.659~3.19	1.50	11.6	0.588~2.83	1.48	7.9
	Composition(g/g)	0.087~0.302	0.156	9.6	0.056~0.429	0.172	9.7	0.091~0.388	0.188	9.6
OC	Concentration(mg/Nm ³)	0.265~5.42	1.83	8.9	0.418~4.12	1.80	9.0	0.311~4.79	1.85	11.3
	Composition(g/g)	0.088~0.463	0.198	11.5	0.060~0.438	0.157	11.4	0.079~0.402	0.173	13.1

a: The rotary speeds were set at four different cruising speeds (i.e. 1000, 1500, 2200 and 3000rpm) to simulate the idling condition and the cruising speeds at 40km/h, 80km/h and 110km/h, respectively.

Table 6. The concentration ratios of OC/TC and OC/EC for carbonaceous aerosols measured from the engine exhaust.

Catalyst Converter	Fuel	Items	Ratio	
			Range	Mean
Without	92-LFG	OC/TC	0.51~0.66	0.59 ± 0.07
		OC/EC	1.21~1.77	1.43 ± 0.19
	95-LEG	OC/TC	0.57~0.78	0.72 ± 0.07
		OC/EC	1.91~2.78	2.55 ± 0.21
	PLG	OC/TC	0.53~0.73	0.69 ± 0.04
		OC/EC	1.83~2.63	2.28 ± 0.20
With	92-LFG	OC/TC	0.51~0.68	0.62 ± 0.04
		OC/EC	1.31~1.82	1.66 ± 0.13
	95-LEG	OC/TC	0.47~0.59	0.54 ± 0.03
		OC/EC	1.12~1.43	1.20 ± 0.12
	PLG	OC/TC	0.46~0.59	0.55 ± 0.04
		OC/EC	1.07~1.45	1.25 ± 0.08

results of our study are almost identical to those of Nunes et al..

6. Conclusions

- (1).The mean total-PAH concentration in the PLG fuel was 80 mg/L, which was approximately 9.0 and 6.8 times higher than those for 92-LFG and 95- LFG, respectively.
- (2).Among the total PAH concentration, 64.2% for 92-LFG, 69.7% for 95-LFG and 97.6% for PLG were contributed by Nap.
- (3).The measured total-PAH concentration for 95-LFG powered engine at four different cruising speeds ranged from 356 to 957 ug/Nm³ and averaged 684 ug/Nm³. This mean value was approximately 33% and 29% higher than those of 92-LFG and PLG, respectively.
- (4).Whether a catalyst converter was adopted or not, it is apparent that PAHs from the primary sources mainly existed in the gas phase.
- (5).Due to the higher operational temperature existing in the conditions of higher driving speed, the total-PAH emission concentration from the 92-LFG, 95-LFG and PLG powered engine decreased with the increase in driving speed.
- (6).Vehicles with catalyst converters could reduce PAHs emission by more than 90%.
- (7)The mean concentrations of both EC and OC in the exhaust of a gasoline-fueled engine were approximately two orders of magnitude higher than those measured in the ambient air of both traffic intersection and rural atmosphere.
- (8).The carbonaceous constituents decreased significantly with the adoption of a catalyst converter. The results showed that vehicles with catalyst converters could reduce carbonaceous emission by more than 50% for TC, 40% for EC and 60% for OC, respectively.
- (9).The average OC/TC ratios for carbonaceous aerosols emitted from the gasoline powered engine were approximately 10% and 44% higher than those measured in the ambient air of traffic intersection and rural area, respectively.

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