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Morphologic and chemical composition of particulate matter in motorcycle engine exhaust

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ABSTRACT

Despite the fact that environmental pollution due to motorcycle exhaust gases reports a great increase, motorcycle production exhibits a great increase through the last years. Countries of Asia and Africa are reported to be the major regions where two-wheeled vehicles are a major transportation mode, with tens of millions of units sold per year. Motorcycle exhaust particles are considered to be the major contributor to environmental pollution due to their airborne dispersion, containing great amount of polycyclic aromatic hydrocarbons (PAHs). This study aims at reporting an objective analysis of the main sources of the ambient air pollution as also particle size distribution and chemical composition analysis of particulate matter originated from the exhausts of two-wheeled vehicles used in the territory of Vladivostok, Russia. Various types of two-wheeled vehicles were examined (motorcycles, ATVs, scooters and wet bikes) using different types of engine and fuel system. Experimental results showed that there was no clear relation to the particle size distribution with the engine displacement of motorcycle and the number of strokes and the fuel system. Instead, there were reported two clear assumptions. The first one is that regarding to the motorcycle brand, a few samples did not exhibit a great percentage of PM_{10} fraction. The second one is that more modern vehicles, that have a harmful gas afterburning system, are usually the source of an increased percentage of PM_{10} emitted particles. At last, it should be mentioned that the laser particle size analysis method is capable of determining the particle sizes after their agglomeration whereas the optical morphometry method allows to determine the real particle size of emissions. In conclusion, it can be pointed out that the agglomeration of particles can lead to the reduction in the toxicity of particles emissions originated from two wheeled-vehicles.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a group of hazardous chemicals, toxic to human health [1–3] while also considered as potent atmospheric pollutants when found in the environment, as many of their compounds have been identified as carcinogenic, mutagenic, and teratogenic to microorganisms [4–7]. According to previously research studies it is reported that due to their high levels of lipophilicity and water-insolubility it is difficult to be degraded by microorganisms [8] which makes their presence in the environment even longer. In urban atmosphere, PAHs are mainly anthropogenic, originated from incomplete combustion of fuels in the engines of transportation means.

According to the literature, various types of vehicles have been examined concerning their pollutant emissions [9–12] where motorcycles and diesel powered cars have proved to be the main sources of maximum emissions of particulate matter, while in many countries it is reported that the major polluting factor of ambient air comes from the emissions of motorcycles, comparing to all transportation modes [13]. Despite the small engine displacement of two-wheeled vehicles, comparing to automobiles, the particulate matter originated from motorcycles' exhaust gases is reported to be greater in amount than PM originated from automobiles while also exhibited stronger PAH-related

Abbreviations: PAHs, polycyclic aromatic hydrocarbons; ICE, internal combustion engines; EDTA, ethylenediaminetetraacetic acid; EFI, electronic fuel injection system; PM, particulate matter; PM_{10}, particles with a diameter between 2,5 and 10 μm; VEPs, vehicle emitted particles; VOCs, volatile organic compounds

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Table 1
List of motorcycles, ATVs, scooters and wet bikes used in the experiment.

No	Coded vehicle model	Displacement(cc)	Year of manufacture	Fuel (Russian standard)	Engine type	Fuel system	Mileage (km)
1	HCB	400	2002	Gasoline AI-95	4-stroke	Carburetor	17700
2	HCRF	450	2005	Gasoline AI-95	4-stroke	Carburetor	130 moto hours
3	HCRF	250	2005	Gasoline AI-95	4-stroke	Carburetor	200 moto hours
4	YYZF	250	2008	Gasoline AI-95	4-stroke	Carburetor	180 moto hours
5	HXr	100	2005	Gasoline AI-95	4-stroke	Carburetor	23000
6	KKXF	450	2008	Gasoline AI-98	4-stroke	Carburetor	120 moto hours
7	SVS	1400	1988	Gasoline AI-92	4-stroke	Carburetor	40000
8	SGSF	400	1992	Gasoline AI-92	4-stroke	Carburetor	80000
9	SGSF	600	1992	Gasoline AI-92	4-stroke	Carburetor	75000
10	SGSXR	1000	1995	Gasoline AI-92	4-stroke	Carburetor	35000
11	YR	1500	1997	Gasoline AI-92	4-stroke	Carburetor	30000
12	HXr	250	1997	Gasoline AI-92	4-stroke	Carburetor	7500
13	KZZR	400	1997	Gasoline AI-92	4-stroke	Carburetor	50000
14	HCB	1300	1998	Gasoline AI-92	4-stroke	Carburetor	30000
15	YGP	1200	2000	Gasoline AI-92	4-stroke	Carburetor	30000
16	YRZ	760	2000	Gasoline AI-92	4-stroke	Carburetor	30500
17	HCB	400	2000	Gasoline AI-92	4-stroke	Carburetor	14514
18	YXjr	1300	2000	Gasoline AI-92	4-stroke	Carburetor	38000
19	YFZS	600	2001	Gasoline AI-92	4-stroke	Carburetor	41000
20	HCB	400	2001	Gasoline AI-92	4-stroke	Carburetor	39000
21	SB	800	2002	Gasoline AI-92	4-stroke	Carburetor	45000
22	HCB	1300	2003	Gasoline AI-92	4-stroke	Carburetor	40000
23	HCB	1300	2005	Gasoline AI-92	4-stroke	Carburetor	35000
24	YYZF	450	2005	Gasoline AI-92	4-stroke	Carburetor	200 moto hours
25	Ksxf	350	2011	Gasoline AI-98	4-stroke	EFI	30moto hours
26	BRPSD	1500	2009	Gasoline AI-95	4-stroke	EFI	150moto hours
27	Ksxf	350	2012	Gasoline AI-95	4-stroke	EFI	100moto hours
28	KU	1500	2012	Gasoline AI-95	4-stroke	EFI	100 moto hours
29	HCBRXX	1000	2003	Gasoline AI-92	4-stroke	EFI	37000
30	SB	1800	2004	Gasoline AI-92	4-stroke	EFI	50000
31	YFJR	1300	2005	Gasoline AI-92	4-stroke	EFI	25000
32	AC	700	2005	Diesel	4-stroke	EFI	140000
33	K	700	2007	Gasoline AI-92	4-stroke	EFI	50moto hours
34	BRPSD	1800	2009	Gasoline AI-92	4-stroke	EFI	28000
35	KU	1400	2009	Gasoline AI-92	4-stroke	EFI	10200
36	YFZ	1800	2010	Gasoline AI-92	4-stroke	EFI	200 moto hours
37	BRPSD	1800	2011	Gasoline AI-92	4-stroke	EFI	220 moto hours
38	KS	1500	2011	Gasoline AI-92	4-stroke	EFI	85moto hours
39	HD	50	1991	Gasoline AI–92 + oil	2-stroke	Carburetor	3100
40	HCR	125	1991	Gasoline AI–92 + oil	2-stroke	Carburetor	180 moto hours
41	HCr	80	1992	Gasoline AI–92 + oil	2-stroke	Carburetor	100 moto hours
42	HCRM	250	1997	Gasoline AI–92 + oil	2-stroke	Carburetor	250 moto hours
43	KSX	250	2012	Gasoline AI–92 + oil	2-stroke	Carburetor	150 moto hours
44	KSX	125	2010	Gasoline AI–95 + oil	2-stroke	Carburetor	100 moto hours

carcinogenicity and indirect mutagenicity than PM from automobiles [14]. The microscale pollution of the ambient air by human sources, caused by internal combustion engines (ICE), has been actively studied in recent years due to their dominant contribution to the environmental [11,12,14,15]. More precisely, the largest contribution is made by the dispersion of micro and nanoscale fractions of the air pollutant emissions of cars and motorcycles [7,16].

Two-wheeled vehicle transportation is one of the most important transportation means in Russia. On a global scale, the most major regions were motorcycles are used are countries of Asian and African continents, with tens of millions of units sold per year. The production of motorcycles in these countries is growing much faster than the production of automobiles, while since 2003 the global production of motorcycles has increased 42%, 75% of which was reported in Asian countries by 2006, while it continues to grow [17]. Pollution of ambient air in nano and micro scale is also a matter of great importance in cities of Russia's Far East. Vladivostok and Ussuriisk are reported to be the cities with the greatest percentages of vehicles used as it is estimated that the ratio of the total number of cars and motorcycles to the total population exceeds 60% [7,18]. In these cities the contribution of exhaust gases of motorcycles to the pollution of the ambient air is quite high. Despite the fact that two-wheeled transportation in the Far Eastern region is seasonal, the number of motorcycles and scooters in the spring-autumn period in residential and adjacent territories counts to a significant number.

Previously reported studies [18–20] have shown that it is possible to estimate the environmental hazard degree of a specific vehicle with in-depth analysis of exhaust emissions of ICE. Specifically, in the exhaust gases of two-wheeled vehicles, an increased content of PAHs and regulated air pollutants (CO, CO_2, HC, NO_x, PM) is found with a wide particle size range of particulate matter [10,15,21]. Till today a great number of research studies have investigated the particle size distribution of vehicle emitted PM and their chemical composition [22–25]. As reported, the toxic effects of particulate matter to human health are strongly connected to the size of particles emitted and their chemical composition. As shown in the past, exhaust emitted particles sized under the PM_{10} and $PM_{2,5}$ fractions can cause various toxicological effects [26,27]. These toxicological effects is also proved to vary according to the chemical composition of PM [28].

Regarding to the type of engine, 2-stroke or 4-stroke, and the type of fuel system used, carburetor or EFI, there have been reported some differences in the amount of emitted exhaust gases. More specifically it has been reported that motorcycles using the EFI fuel system emit lower amount of air pollutant particles than motorcycles using carburetor fuel systems [15], which leads to the conclusion that two-wheeled vehicles using the EFI fuel system are environmentally safer than those using the carburetor. In relevant studies it has been reported that particles emitted from 2-stroke engines tend to be more toxic than 4-stroke

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