Benzene Toluene and Xylene in Exhaust from Motorcycles

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Abstract

In this study, benzene, toluene and xylene from gasoline and exhaust emission were measured for 44 in-use motorcycles. The motorcycle samples were considered based on both engine type (two and four-stroke) and engine age (old, moderately old, and new). The age of engine was determined as follow: new motorcycles were those which were less than 5 years old, moderately old motorcycles were in range of 5-10 years old and old motorcycles were more than 10 years old. Tedlar bag was used to collect the sample of exhaust emission at idle condition. The samples were analyzed using gas chromatography with flame ionization detection (GC/FID). The study revealed that the two-stroke motorcycles emitted hydrocarbon (benzene, toluene and xylene) about 3-4 times higher than the averages of four-stroke motorcycles. The average concentrations of benzene, toluene and xylene from the old two-stroke motorcycles were found to be 116.2, 261.7 and 39.2 ppm respectively. For new four-stroke motorcycles, the concentrations of the three chemicals were found to be 11.7, 29.0 and 7.6 ppm respectively. These results indicate that there was a significant increase in air pollutant emissions with engine age at significant level (α) = 0.05.

1. Introduction

Air pollution is one of the most obvious and important environmental problems in many cities of the world including the Bangkok Metropolitan Area. Urbanization and rapid development of Bangkok have resulted in a great demand for an effective transportation system and traffic management. However, inadequate road infrastructure and the lack of sufficient mass transit system have intensified this problem, as they encourage people to travel by their own private vehicles. In 1998, the total numbers of vehicles registered in the Bangkok Metropolitan Area were more than 3.8 million while the road space as a share of total area in Bangkok is only 11%, which is substantial lower than international standard of between 20% to 25% [1]. The more transport requirement leads to more fuel being burned, and it leads to a higher level of exhaust emission released into the atmosphere.

In addition to their adverse effects on human health, motor vehicles emissions have been associated with serious environmental problems such as photochemical smog [2]. Motor vehicle especially motorcycles emit various types of air pollutants such as carbon monoxide, hydrocarbons, nitrogen oxides, sulfur dioxide and particulate matter. Traditionally, the measurements of mobile source emission were limited to total hydrocarbons (THC), carbon monoxide (CO), and oxides of nitrogen (NO_x). Nowadays, The Government of Thailand has banned leaded gasoline and substituted unleaded one since 1994. Unleaded gasoline uses aromatic compounds to increase the octane number and they mainly are benzene, toluene, xylene, and ethyl benzene. These pollutants worsen the air quality in Bangkok and adversely affect human health [3]. In Bangkok, motorcycles are a major source of air pollution because this type

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of vehicle is extensively used due to its low cost and convenience. There were 13,214,051 motorcycles in Thailand at the end of 2004, of which 1,593,685 (12 %) were used in Bangkok [4].

Several of studies are concerned about the hydrocarbons from motor vehicles. C_3-C_{10} hydrocarbons were investigated in the atmosphere of Athens, Greece [5]. In this study the aromatic fraction predominates with maximum benzene and toluene concentrations of 19 and 39 ppbv, respectively. Through comparison with non-methane hydrocarbon (NMHC) emission profiles of other cities, it was concluded that vehicle emission was the main sources of the observed NMHC. The volatile organic compounds (VOCs) monitoring was conducted at Yaowaraj, Bangkok [6]. The highest benzene and toluene concentrations were found in the place where heavily congested traffic condition predominated. In the same study benzene and toluene concentrations for weekday and daytime were shown to be considerably higher than weekend and nighttime respectively. The concern of VOCs is presented in the form of limiting value in the ambient air in many standards, for example, United State Environmental Protection Agency (US.EPA), and World Health Organization (WHO) [6].

There are several factors which affect the concentration of exhaust emissions such as type of vehicle, state of the motor, the quality of the fuel and lubricating oil, the load of the vehicle, the number of kilometers driven per year per vehicle, and speed of travel. It is the fact that there were insufficient previous studies regarding these factors in Thailand, which led to this study.

2. Material and Method

2.1 Material

2.1.1 Sampling apparatus

Sampling apparatus were 20 liter Tedlar sampling bag, black plastic bag, purified nitrogen gas (N_2), temperature detector, vacuum box, air pump, Teflon tube, moisture trap scrubber with the moisture trap substance, magnesium perchlorate ($Mg(ClO_4)_2$), and three-way valve.

2.1.2 Motorcycles

The 44 motorcycles used in this study were two and four-stroke motorcycles with engine displacement size of 100-150 cc. The three groups of samples were classified by the age of use as Table 1.

Table 1. Types and Numbers of Motorcycles

Type	Total Number	2-stroke	4-stroke
Old motorcycle	11	7	4
Moderate age motorcycle	16	10	6
New motorcycle	17	10	7
Total	44		

The fuel used in this study was unleaded gasoline only. The brand of gasoline used and its octane number were not specified. It might be 91 (regular grade) or 95 (premium grade) depending on remaining fuel in fuel tank of each motorcycle.

2.1.3 Sample Analysis

The gas sample was analyzed by Gas Chromatography: Hewlett Packard 5890 series II with Flame ionization detector (FID).

2.2 Methods

2.2.1 Exhaust Gas Sampling

In this study, only benzene, toluene, and xylene (ortho-, meta- and para- xylene were included as total xylene) were measured. All emission samples were collected from the motorcycles at idle mode condition only. Before each sampling and measurement, the motorcycle was warmed up for at least 10 minutes and the temperature at the end of exhaust pipe would not be less than 50 ^{0}C.

The Tedlar sampling bag was washed by purified N_2 (99.999%) at least three times before use. The exhaust sample was pumped into 20 liter Tedlar bag that was also covered by a black plastic bag to prevent an occurrence of photo-oxidation reaction.

The method and quality assurance of air sampling and analysis were followed that of Lodge [7].

2.2.2 Gasoline Sampling

The gasoline sample was collected by using a plastic tube to withdraw the gasoline from fuel tank directly. The gasoline sample in vial was approximately 5 ml and then it was immediately kept in the refrigerator at 20 ^{0}C for laboratory analysis later.

2.2.3 Sample Preparation and Analysis

After sampling, the exhaust gas samples in the Tedlar bags and the gasoline samples in vials were brought to the chemical laboratory at STREC (Science and Technology Research Equipment Center of Chulalongkorn University) for the analysis of benzene, toluene and xylene by Gas Chromatography with Flame Ionization Detection (GC/ FID). All exhaust gas samples were taken to the laboratory for analyzing within 3 hours after collecting.

2.3 Study period

This study was conducted during October 1999 to March 2000.

3. Results and Discussion

In this study, the concentration of the benzene, toluene, and xylene (BTX) in the exhaust of different groups and different engine types of motorcycles were investigated and compared. The concentrations of BTX in gasoline from fuel tank of each motorcycle were also analyzed. In addition, the effect of engine age and engine type on the BTX concentrations in emissions were studied by using statistical analysis as well.

3.1. The Concentrations of BTX in Exhausts

The average concentrations of benzene, toluene and xylene in each group were shown in Table 2.

Table 2. Averages concentrations of BTX

Ages of motorcycle	Benzene(ppm)		Toluene(ppm)		Xylene(ppm)	
	Two-stroke	Four-stroke	Two-stroke	Four-stroke	Two-stroke	Four-stroke
Old	116.2	32.9	261.7	93.2	39.2	21.5
Moderate	108.6	30.6	219.8	45.6	30.6	7.9
New	83.2	11.7	192.8	29.0	29.9	7.6

3.2 The comparison of BTX concentration ratios between exhausts and gasoline samples.

The ratios of average benzene, toluene and xylene concentrations in gasoline samples to exhausts from two and four-stroke motorcycles were shown in Table 3 and 4. Table 2 shows that BTX emissions in two-stroke motorcycle were greater than the four-stroke motorcycle on average. Table 3 and 4 also show that old motorcycles (both two and four-stroke) released more hydrocarbons than the new ones.

3.3 Engine type and BTX concentrations

The lowest concentrations of benzene, toluene and xylene in this study were found in four-stroke motorcycles of all engine ages. The average benzene, toluene and xylene concentrations from the samples of two-stroke motorcycles were much higher (approximately 3-4 times) than the emissions from four-stroke motorcycles due to the difference of their combustion process. The loss of part of the unburned fuel through the exhaust valve was a major reason for the very high hydrocarbon emission of two-stroke motorcycle engine. Another major reason for high Hydrocarbon emissions from two-stroke motorcycles was their tendency to misfire under low load condition.

3.4 Engine age and BTX concentrations

The average concentrations (in Table 2) of benzene, toluene and xylene for emissions of the older motorcycles are slightly greater than the newer motorcycles. This result shows the possibility of that engine's age has an effect on pollutant concentrations in motorcycle exhaust. The explanation of this finding might be from the old engine has the tendency to have a poor or a lack of maintenance by a lapse of time. This may cause the incomplete combustion process in the engine and lead to the higher emission in old engine.

Table 3. Ratios of the average BTX concentrations in gasoline to the average BTX concentrations in the exhaust of two-stroke motorcycles.

Age of engine	Two-stroke motorcycle								
	Benzene (ppm)			Toluene (ppm)			Xylene (ppm)		
	Gasoline	Exhaust	Ratio of gasoline to exhaust	Gasoline	Exhaust	Ratio of gasoline to exhaust	Gasoline	Exhaust	Ratio of gasoline to exhaust
Old	12600	116	109:1	74934	262	286:1	38468	39	986:1
Moderate	12450	109	114:1	97932	220	445:1	35239	31	1137:1
New	15183	83	183:1	85236	193	441:1	26334	30	878:1

Table 4. Ratios of the average BTX concentrations in gasoline to the average BTX concentrations in the exhaust of four-stroke motorcycles.

Age of engine	Four-stroke motorcycle								
	Benzene (ppm)			Toluene (ppm)			Xylene (ppm)		
	Gasoline	Exhaust	Ratio of gasoline to exhaust	Gasoline	Exhaust	Ratio of gasoline to exhaust	Gasoline	Exhaust	Ratio of gasoline to exhaust
Old	11489	33	348:1	76670	93	824:1	41981	22	1908:1
Moderate	12053	31	389:1	80320	46	1746:1	35256	8	4407:1
New	11335	12	945:1	82310	29	2838:1	37457	8	4682:1

3.5 Effect of engine type and engine age on BTX in exhaust

In this study, the statistical two-way analysis of variance (2-way ANOVA) was used to analyze the influence of engine types (two and four-stroke) and age of engine (old, moderate and new) on BTX concentrations in motorcycle's emission. The statistical programming, SPSS version 6.0 for MS windows, was used to examine the interaction of 2 factors (engine type and engine age) on the concentrations of BTX in emissions.

The calculated results from the SPSS showed that the age of engine (old, moderate and new motorcycles) has an effect on the motorcycle's pollutant emission. The older motorcycles emitted more BTX in exhaust gas than the new ones. The statistical analysis indicated that there was a significant increase in air pollutant emissions with engine age at significant level (α) = 0.05.

In addition, the engine type (two and four stroke motorcycles) had even more strongly effect on the pollutant emission. The concentrations of BTX components in exhaust gas from two-stroke engine motorcycles were also found to be several times higher than the four-stroke engine motorcycles (Table 2), depending on the species of BTX.

The relationship of type and age of motorcycle on the pollutants in exhaust emission in this study was in line with others [8-10]. The previous study was also showed that the air pollutant levels associated with traffic volume and the concentration emission from two-stroke was higher than four-stroke

engine vehicle [8]. The study conducted in 1991 on the exhaust gas from gasoline engines found that the concentrations of hydrocarbon components in gas samples from two-stroke engine motorcycles were higher than the four-stroke engine motorcycles, and the benzene, toluene and xylene were major aromatic hydrocarbons found in exhaust samples from both two and four-stroke engine motorcycle [9]. The previous research paper conducted in Bangkok on the exhaust emission from gasoline-powered motor vehicles which were performed on chassis dynamometer revealed that there was a significant increase in hydrocarbon emissions with increasing car mileage and earlier model years in a fleet of 10 vehicles of different model years and manufacturers [10].

Conclusion

The conclusions of the study could be summarized as follows:

1. The average concentrations of benzene, toluene, and xylene in exhaust emissions of two-stroke motorcycle were about 3-4 times larger than that of the four-stroke motorcycle.

2. Benzene, toluene and xylene concentrations in exhaust emission of the older motorcycle were higher than the newer motorcycle.

3. Both type and age of engine had more influence on benzene, toluene, and xylene concentrations in motorcycle emission.

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