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Influence of Gasoline Aromatic Content on Air Pollutant Emissions from Four-Stroke Motorcycles

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ABSTRACT

A new four-stroke carburetor motorcycle engine without any engine adjustments was used to study the impact of fuel aromatic content on exhaust emissions of criteria air pollutants (CO, THC, and NO_x). Three aromatic fuels were tested, containing 15, 25, and 50% (vol) aromatics mixed with gasoline. A commercial unleaded gasoline was also tested as a reference case (RF). The experimental data indicated that a lower aromatic content (25 and 15 vol%) in gasoline reduced the amounts of THC and NO_x by more than 10% compared to the reference fuel (aromatic content 30 vol%). CO emissions, on the other hand, did not appear to be related to the aromatic content of gasoline. The excess air ratio (λ) values for the aromatic test fuels were lower than 1.0, i.e., under fuel-rich conditions, and CO emissions increased due to lack of oxygen. In contrast, high NO_x emissions appeared in a near stoichiometric air-fuel ratio, and decreased as the fuel mixture approached lean or rich conditions. The results also showed that decreasing the aromatic content from 50 to 25 and 15 vol% in gasoline may result in a reduction of benzene emissions from the motorcycles without a catalyst converter. This study shows that decreasing the aromatic content in gasoline may reduce the emissions of THC, NO_x, and benzene, but not CO, from four-stroke carburetor motorcycles.

Keywords: Gasoline composition; Chassis dynamometer; Exhaust emissions; Excess air ratio.

INTRODUCTION

Worldwide urban air pollution is estimated to be responsible for 865,000 premature deaths every year and about 60% of these deaths occur in Asia (World Health Organization, 2007; Colbeck *et al.*, 2011). Gasoline vehicles (including passenger cars and motorcycles) are important contributor of the air pollution in urban areas (Srivastava *et al.*, 2008; Tsang *et al.*, 2008; Zhang *et al.*, 2008; Chien *et al.*, 2009). Many Asian countries, such as China, India, Indonesia, Taiwan, and Thailand, have a large and growing number of low engine capacity motorcycles (motorcycles with two- or four-stroke engines). Motorcycles with displacements of 50–125 cm^3 are far more popular than heavy-duty motorcycles (displacement > 250 cm^3) in Taiwan and other Asian countries. Small motorcycles have carburetor engines with a single cylinder and do not have electronic fuel injection systems. Carburetor engines often change the air-fuel ratio for different working conditions, and this significantly influences exhaust emissions. In addition, motorcycle designs are simpler than automobile designs with regard to aspects such as the number of cylinders, engine cooling system, rotational speed, and fuel supply system. The result is power generation procedures that are not as complete as those in automobiles, and that may contribute to poor engine combustion efficiency. Furthermore, because motorcycles are smaller and lighter than cars, and are used primarily to travel short distances at lower speeds, there are significant differences in both fuel consumption and pollutant emissions (Didyk and Moyano, 2001; Tsai *et al.*, 2003).

In addition to engine technology, fuel composition is also a key factor affecting air pollutant emissions from vehicles. When gasoline burn in an engine the main air pollutants present in the exhaust gases are incomplete combustion oxides of hydrocarbon containing CO, NO_x, HC, and particulates (Pilusa *et al.*, 2012). Changes in gasoline composition can reduce vehicle emissions because certain gasoline modifications allow engines to perform at their optimum level. Understanding the impact of fuels on modern gasoline-powered vehicles is important for environmental agencies that develop regulations for reformulated gasoline.

The effect of gasoline composition on vehicle exhaust emissions has been investigated since the early 1990s. Two large-scale studies, the Air Quality Improvement Research

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Program (AQIRP) by automobile and oil companies in the United States in 1989, and the European Programme on Emission, Fuels, and Engine Technologies (EPEFE) by the European Commission in1992, were conducted to evaluate the impacts of gasoline composition on exhaust emissions and air quality. The experimental design and results of AQIRP and EPEFE have been reported in previous articles (Pahl and McNally, 1990; Koehl *et al.*, 1991; Gorse *et al.*, 1992; Rutherford *et al.*, 1995; Goodfellow *et al.*, 1996; McArragher *et al.*, 1999). Furthermore, in order to understand the effects of lead-free gasoline and reformulated gasoline on vehicle exhaust emissions, several studied have been conducted using various vehicle modes (different model year, new and in-use, or passenger cars and light-duty trucks) to quantify their effects (Perry and Gee, 1995; Zervas *et al.*, 2003; Schifter *et al.*, 2004; Yucesu *et al.*, 2006; Chen *et al.*, 2011). The fuel variables examined include sulfur, aromatics, olefins, and benzene, as well as oxygenated additives (MTBE, ethanol, methanol etc.) and Reid vapor pressure. In general, the results of those studies indicated that exhaust emissions of CO, THC, and NO_x are related to the sulfur and aromatic content in gasoline.

However, almost all of the fuel-effect studies were conducted by using passenger cars, and research has rarely focused on motorcycles. For low engine capacity (less than 150 cc.) motorcycles in particular, little data that shows the effects of fuel composition on exhaust emissions is available (Prati *et al.*, 2000; Yao *et al.*, 2008), and thus there is a clear need for more work on this. Based on the results in the literature, the aromatic content of gasoline affects exhaust CO, THC, and some toxic emissions. However, no consistent correlations have been shown between aromatic content and emission variance. Gasoline is a complex mixture of 200 to 300 hydrocarbons, and its properties will differ depending on which of the various refining and blending processes were used to make it. This may contribute the different compositions of aromatic compounds in gasoline.

Consequently, in this study the aromatic content of gasoline was manipulated to evaluate the possible impact of fuel composition on criteria air pollutant emissions from a motorcycle with a four-stroke engine. Three kinds of gasoline with different levels of aromatic content were tested, and the results with regard to the emission of criteria air pollutants were then compared using commercial gasoline as a reference.

EXPERIMENTAL METHODS

Test Fuels

Previous studies have shown that the fuel aromatic content ranges from 50 to 10 vol% (Prati *et al.*, 2000; Schifter *et al.*, 2004; Yao *et al.*, 2008). Three test fuels were designed in this study. They were 1) 15% (A15), 2) 25% (A25), and 3) 50% (A50) by volume aromatics, and represented the low, medium, and high level of aromatic content in gasoline, respectively. A commercial unleaded gasoline was used as the reference fuel. The four fuels were then prepared by the largest petroleum refinery in Taiwan (China Petroleum Corporation, CPC). The compositions of these fuels were measured by CPC using the American Society for Testing Materials (ASTM) procedure. According to the results of the ASTM analysis, the aromatic content was 16.7, 23.9, and 52.9 vol% for A15, A25, and A50, respectively. The properties of all test fuels are summarized in Table 1.

Test Motorcycle

A new four-stroke engine motorcycle, with a displacement of 125 cm^3 and weight of 101 kg, was used in the experiments. The fuel supply system was a carburetor, the cooling system was air-cooling, and the ignition system was capacitive discharge ignition with a single cylinder arrangement. The compressor ratio of the engine was 8.6 at maximum power. The motorcycle was a non-catalyst model without any engine adjustments. This model was chosen in order to accentuate the effects of the aromatic content during testing.

We compare our data of commercial gasoline (RF) with the motorcycle model certification data released from Taiwan EPA with the sample size 180 (TEPA, 2008) to show the representative of the test motorcycle. The mean values of motorcycle certification data from Taiwan EPA are 3.2 ± 1.2 g/km for CO and 0.9 ± 0.2 g/km for HC + NO_x. Our data are 3.0 and 0.9 for CO and HC + NO_x, respectively. It implicates that the test motorcycle in this study is representative among the motorcycle population in Taiwan.

Test Procedures

A regulatory test procedure, CNS 11386, was used for the motorcycle emission test (TEPA, 2001). This is the

Table 1. Properties of test fuels.

Fuel property	Test Fuel			
	RF[a]	A15[b]	A25	A50
Research octane number	95.0	97.0	97.3	98.6
Oxygen content (wt%)	1.8	1.57	1.24	1.08
Aromatic content (vol%)	29.9	16.7	23.9	52.9
Paraffins (vol%)	10.6	5.5	5.6	6.4
Olefins (vol%)	10.6	9.4	11.6	9.2
Naphthenes (vol%)	5.9	4.12	4.4	4.31
Benzene (vol%)	0.6	0.3	0.5	0.9
Gross heating value (J/g)	2560	2570	2620	2580

[a] RF is a commercial unleaded gasoline.
[b] A15, A25, and A50 have 15, 20, and 50% v/v aromatic content in the gasoline, respectively.

same test used by the Economic Commission for Europe cycle (ECE40 cycle). One complete test cycle (780 s) includes idle (240 s), acceleration (168 s), cruising (228 s), and deceleration (144 s) stages. The total distance of this test was 4 km, with average and maximum speeds of 19 and 50 km/h, respectively.

Emission tests were performed on a chassis dynamometer, which is a vehicle certification test by US EPA (Wang *et al.*, 2012), in the certified laboratory of a local motorcycle manufacturer. The main system was composed of a chassis dynamometer (MEIDEN, 20KW), a dilution tunnel, a constant volume sampler (CSV) unit (HORIBA, CVS-51S), and an exhaust gas analyzer (HORIBA MEXA-7200). Vehicle details (registration number, maker, category, and test weight) were entered into the dynamometer control computer for identification and calculation of inertia loading for the vehicle. The information was then saved to a dedicated file from which the test cycle was referenced in order to set the correct speeds and loads during testing. The motorcycle was placed on a chassis dynamometer and was left at room temperature for 6 hours prior to the start of the cold-start testing process. The test room temperature was controlled at between 20–30°C.

Prior to each emissions test, a fuel change protocol was followed to ensure minimal crossover between the test fuels and consistency between tests. The fuel tank was first drained, then one liter of the new test fuel was added to the tank, the engine was allowed to idle for five minutes to allow the new test fuel to thoroughly flush through the fuel supply system, and the tank was then drained again. Two liters of the new fuel were then added for the emissions test.

Exhaust Sampling and Analytical Procedures

The sampling and measurement equipment for air pollutants were similar to those used in our previous works (Yao *et al.*, 2009; Yao *et al.*, 2011). For criteria air pollutants, the tailpipe of each motorcycle was connected directly to a sampling bag system for the entire cycle. The mixture exhaust gas was initially mixed with air, directed to the CVS unit, and then connected to the sampling bags and analyzer. After sampling, criteria pollutant emissions were measured as follows: CO with a non-dispersive infrared analyzer, THC with a flame ionization detection analyzer, and NO_x (NO and NO_2) with a chemiluminescence detection analyzer. Calibration gases (CO, C_3H_8, NO, and CO_2) were mixed with pure nitrogen (> 99.95%). All measuring instruments had a precision of ± 3%.

The background pollutant concentrations were also analyzed routinely and deducted from the test results. The results indicated that the background concentrations were approximately 1 ppm for CO, 4 ppm C for THC, 0.1 ppm for NO_x, and 0.04% for CO_2, which were much lower than those of the sample gas.

The excess air ratio (λ) in each test was measured for different speeds, i.e., idle, 15, 30, and 50 km/h, using an automotive emission analyzer (HORIBA, MEXA-584L) which is part of the emission test system in the dynamometer. The λ is defined as:

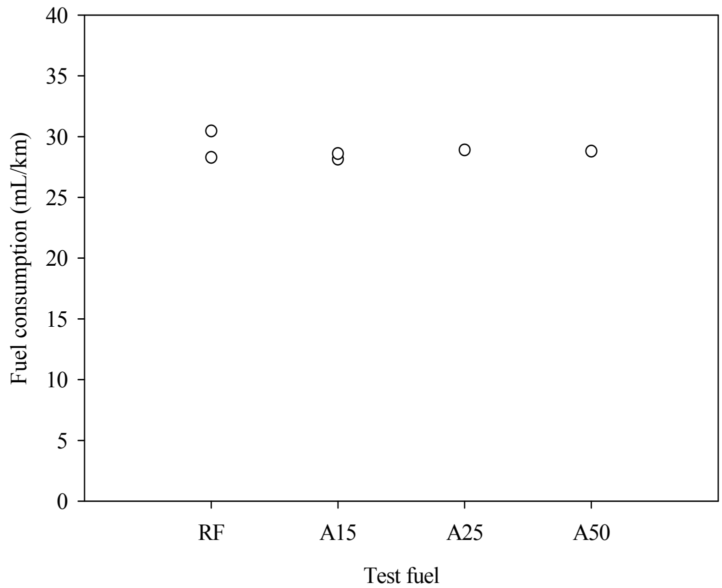
$$\lambda = AFR_{act}/AFR_{st} \quad (1)$$

where AFR_{act} is the actual AFR and AFR_{st} is the stoichiometric AFR of the test fuels. Thus, the $\lambda < 1$ denotes fuel-rich and $\lambda > 1$ denotes fuel-lean operations.

RESULTS AND DISCUSSION

Effects on Fuel Consumption and Combustion Stability

Fig. 1 shows the fuel consumption of the aromatic test gasoline and the reference fuel in the test motorcycle. The mean fuel consumption value was 28.4, 28.9, and 28.8 mL/km for the A15, A25, and A50 blends, respectively,



Note: RF is a commercial unleaded gasoline; A15, A25, and A50 have 15, 25, and 50% v/v. aromatic content, respectively.

Fig. 1. Fuel consumption (mL/km) of aromatic test fuels by the four-stroke motorcycle.

and was 29.3 mL/km for the RF. The A15 blend provided the best fuel consumption (28.4 mL/km), it was 3% lower than that of the RF. However, for the A25 and A50 blends, fuel consumption showed no significant change with a variance of approximately 1.5 and 1.8%, respectively. In general, the aromatic content of fuel showed no relationship with fuel consumption.

Fuel properties data show that the gross heating values of the test fuels from low to high were 2560 J/g (RF), 2570 J/g (A15), 2580 J/g (A50), and 2620 J/g (A25). More fuel needed to be introduced into the engine cylinder when fuel had a low heating value. The low level of variance in the heating value (less than 2%) of each test fuel may have contributed to the lack significant differences in fuel consumption for gasolines with different aromatic content.

In order to understand the combustion stability of the test motorcycle, CO_2 emissions were measured in grams per liter of fuel. The CO_2 emissions were 2120 g/L-fuel for the commercial fuel (RF) and 2170, 2110, and 2120 g/L-fuel for A15, A25, and A50, respectively. The variances were 2.0% (A15), 0.5% (A25), and 0.02% (A50) as compared to the RF. This implies that the combustion stability of the tested motorcycle was good.

In brief, there was no difference in fuel consumption for gasolines with different aromatic content, and this may be due to the low variance of the heating value of the aromatic test fuels. Moreover, the results of the CO_2 emissions measured in grams per liter of fuel imply that the combustion stability of the tested motorcycle was good when using the aromatic test gasolines.

Emissions of Criteria Air Pollutants

CO Emissions

The emission factors (g/km) of regulated pollutants for aromatic-content gasolines for the entire test cycle are presented in Table 2. The highest CO emissions appeared to come from the A25 test fuel (3.23 g/km), followed by A50 (3.17 g/km), RF (3.05 g/km), and A15 (2.99 g/km). A25 and A50 fuels increased CO emissions by 6 and 4%, respectively, compared to the RF. However, the CO emissions showed no change in the case of A15 fuel (variance is 2%). Fig. 2 illustrates the emission factors of the test fuels which were calculated using a fuel-base, i.e., g/L-fuel. The CO emission factor ranged from 105 to 112 g/L-fuel for the three aromatic fuels, and was 104 g/L-fuel for the RF. The A25 fuel had the highest level of CO emissions among the test fuels, followed by A50, A15, and RF. CO emissions from the aromatic fuels were 2% to 8% greater than those from the RF.

From the results listed in the previous section it can be seen that low aromatic content in gasoline (A15 and A25 fuels) slightly increased CO emissions compared to the reference fuel (aromatic content 30 vol%). Practically, it is impossible to prepare test fuels which change the aromatic content while keeping the other parameters constant. Other test fuel compositions may also influence exhaust pollutant emissions. The correlations between the exhaust pollutant level (mass/L-fuel) and the fuel compositions (paraffins, olefins, naphthenes, aromatics, benzene, and oxygen contents) are evaluated to present the influence of each fuel compositions. Table 3 shows the correlation coefficients (r) between the emissions and each fuel property for the aromatic test fuels. The correlation coefficients (r) between CO emissions and each fuel property indicated that CO was only related to the fuel oxygen content for all fuel compositions, with a value of 0.92.

The change of fuel composition may affect the air-fuel ratio and result in variations in the combustion process and air pollutant emissions (Taylor *et al.*, 1996). Thus we also measure the excess air ratio (λ) to discuss the engine combustion condition. The values of the excess air ratio (λ) under idle conditions were 0.93 for the RF, 0.88 for A15 and A25, and 0.85 for A50 (see Fig. 3). In the driving pattern, the λ values ranged from 0.75 (A25) to 1.04 (RF). Since the test motorcycle could not adjust the rate of air intake into the engine, the engine operated under rich mixture ($\lambda < 1$) conditions while using the aromatic test fuels, except in the case of the RF fuel. Under fuel-rich conditions, CO emissions increase due to lack of oxygen. Aromatics may produce higher CO concentrations under

Table 2. Emission (g/km) of criteria pollutants for aromatic gasolines from a four-stroke motorcycle.

Test fuel[*1]	Aromatic content (vol%)	Emission factor (g/km)		
		CO	THC	NO_x
RF-1		2.94	0.64	0.26
RF-2		3.15	0.65	0.30
Average (n = 2)	29.9	3.05	0.65	0.28
RPD(%)[*2]		6.9	2.6	15.7
A15-1		2.88	0.52	0.24
A15-2		3.10	0.55	0.22
Average (n = 2)	16.7	2.99 (–2%)[*3]	0.54 (–17%)	0.23 (–18%)
RPD(%)		7.2	5.4	5.2
A25	23.9	3.23 (6%)	0.56 (–13%)	0.23 (–18%)
A50	52.9	3.17 (4%)	0.57 (–11%)	0.24 (–14%)

[*1] RF is a commercial unleaded gasoline; A15, A25, and A50 have 15, 25, and 50% v/v. aromatic content in the fuel, respectively.

[*2] RPD: Relative percent difference.

[*3] Values in parentheses ( ) show the emission variance of each test fuel as compared to the emissions for the RF.

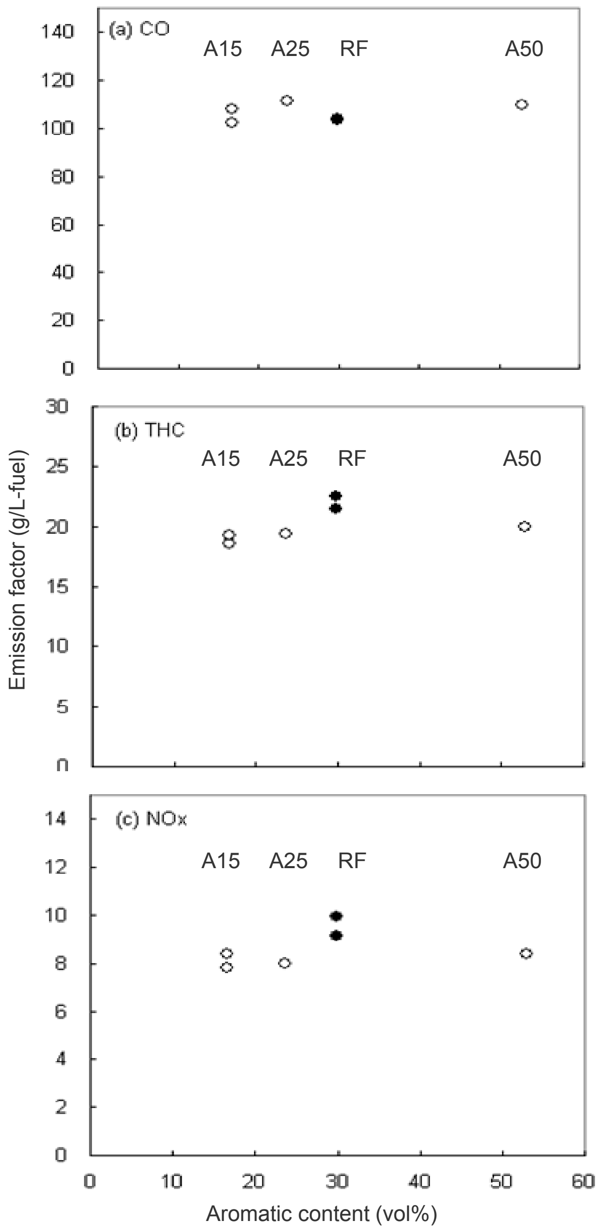


Fig. 2. Emission (g/L-fuel) of criteria pollutants from the four-stroke motorcycle using aromatic gasolines.

fuel-rich conditions (Zervas *et al.*, 2003). The test engine operating under rich mixture ($\lambda < 1$) conditions while using aromatic fuels may be one reason why no CO emission reduction was observed compared to the RF in this study.

In brief, the experimental data indicated that the CO emissions from a four-stroke motorcycle engine are greatly influenced by the excess air ratio (λ). Lambda (λ) is more important than fuel composition for CO emissions. This finding is in agreement with those of previous studies (Goodfellow *et al.*, 1996; Zervas *et al.*, 2003).

THC Emissions

The lowest THC emission was 0.54 g/km for the A15 test fuel in the test motorcycle. Compared with the RF (aromatic content 30 vol%), the results indicate that the A15 (aromatic content 17 vol%) and A25 (aromatic content 24 vol%) may reduce THC emissions by 13 and 17%, respectively. As expected, the low-aromatic content fuel showed fewer THC emissions, however, the fuel with the highest aromatic content (A50) also showed a THC emission reduction (about 11%) compared to the RF. The fuel-base emission factor ranged from 19 to 20 g/L-fuel for aromatic fuels, and was 22 g/L-fuel for the RF. THC emissions from A15, A25, and A50 were 14, 12, and 9% lower than those from the reference fuel, respectively.

In addition to aromatic content, other fuel compositions may also affect THC emissions (Schuetzle *et al.*, 1994; Zervas *et al.*, 2003). The results of the correlation coefficient (r) between THC emissions and each fuel composition (Table 3) showed a strong positive correlation ($r > 0.7$) between THC emissions and the paraffin and naphthene contents of gasoline. The correlation coefficients were 0.98 and 0.97 for the fuel paraffin and naphthene contents, respectively. These findings imply that there is an interrelation between the THC emissions of paraffin and naphthene, but no relation with other fuel compositions was found in our test fuels.

The λ values of the aromatic test fuels were lower than 1.0 (Fig. 3), i.e., the engine operated under fuel-rich conditions. Under fuel-rich conditions more THC is emitted than under stoichiometric conditions, due to a lack of oxygen (Schuetzle *et al.*, 1994; Zervas *et al.*, 2003). However, our observations indicated the opposite, that THC emissions were low under fuel-rich conditions. This may have been caused by the same phenomenon that affected CO emissions, i.e., the λ values of the A15 fuel were close to 1 for the three aromatic fuels (more oxygen than the other two fuels) and resulted in low THC emissions. Moreover, since the test engine is not a computerized fuel injection system, the fuel supply could not be immediately adjusted according to the combustion conditions. According to the above experimental data, we assume that THC emissions are influenced by fuel composition more than air fuel ratio.

NO_x emissions

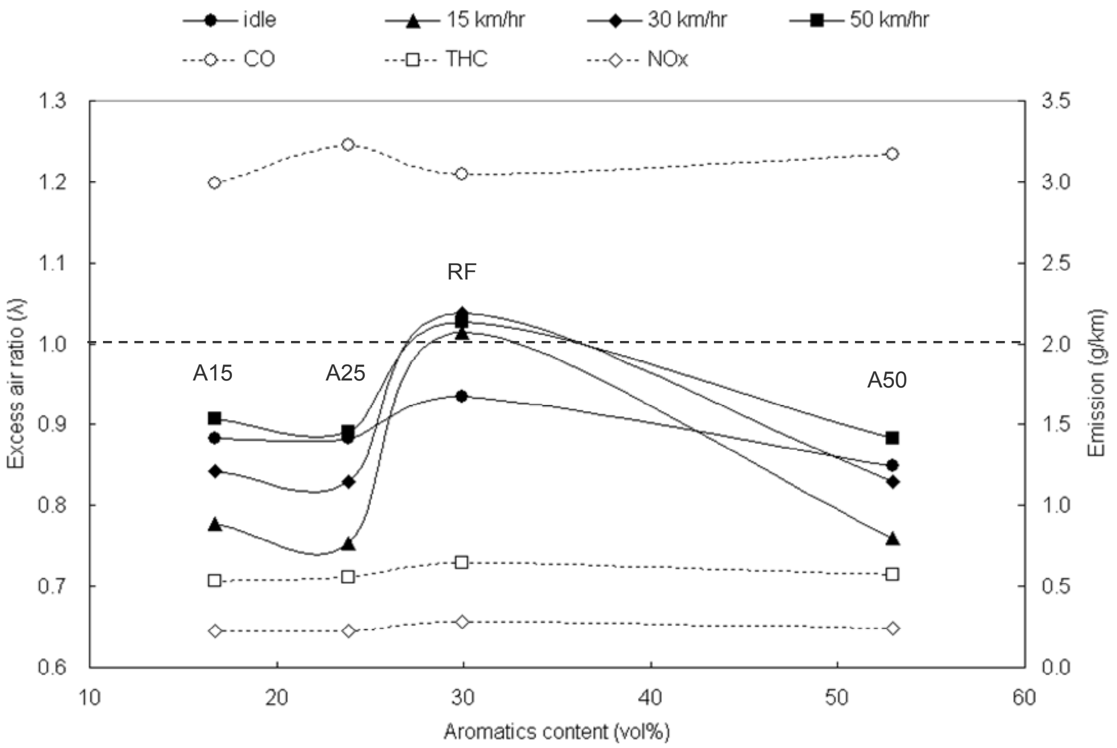
In general, there was a decreasing trend in NO_x emissions as low aromatic content gasolines were used in the test motorcycle. The aromatic fuels emitted NO_x from 0.23 to 0.24 g/km, compared to the 0.28 g/km emitted by the reference fuel. NO_x emissions from low aromatic content fuels were about 14–18% less than those from the reference fuel. The NO_x emission factor by fuel consumption ranged from 8.0 to 8.4 g/L-fuel for the aromatic fuels and was 9.5 g/L-fuel for the RF. The A20 fuel had the lowest NO_x emissions among the test fuels. A15, A25, and A50 had 15, 16, and 12% less NO_x emissions that the reference fuel, respectively.

Aromatic hydrocarbons have higher combustion temperatures than alkanes. Increasing the aromatic content in fuel may cause higher peak flame temperatures and improve combustion efficiency, but can also result in increased NO_x emissions. Moreover, the replacement of aromatics with paraffin should result in lower engine-out NO_x emissions (Schuetzle *et al.*, 1994). The test fuel

Table 3. The correlation coefficients of emissions and fuel properties of the aromatic test fuels.

Fuel property \ Correlation coefficients (r)[*1]	CO	THC	NO_x	Benzene
Oxygen content[*2]	**–0.917**[*3]	0.597	0.711	**–0.826**
Paraffin content	–0.654	**0.984**	**0.989**	**1.000**
Olefins content	0.293	0.179	0.005	–0.466
Naphthenes content	–0.599	**0.969**	**0.950**	0.319
Aromatic content	0.335	0.258	0.188	**0.998**
Benzene content	0.326	0.255	0.189	**0.999**

[*1] strong correlation: r > 0.7, moderate correlation: 0.7 > r > 0.3, and weakly correlation: r < 0.3; correction coefficient of fuel property content and pollutant emission (mass/L-fuel) was calculated by using RF, A15, A25, and A50.
[*2] MTBE was added to all the aromatic test fuels as oxygenated additive.
[*3] bold type implies a strong correlation between emissions and the fuel property.



Note: the emissions of CO, THC, and NO_x were measured under the entire test cycle.

Fig. 3. Excess air ratios (λ) of the aromatic test fuels at various speeds (idle, 15, 30, 50 km/hr).

properties indicate that the paraffin contents of the aromatic test fuels (5.5–6.4 vol%) were lower than that of the reference fuel (10.6 vol%). The correlation coefficients (r), shown in Table 3, between the NO_x emissions and the paraffin and naphthene fuel contents indicate a strong relationship, with coefficients of 0.99 and 0.95, respectively, for the test motorcycle. According to our results, lowering the paraffin content in gasoline may also affect NO_x emissions.

Lambda (λ) is also important parameters for NO_x emissions (Zervas *et al.*, 2003). In general, high NO_x emissions appear in fuels in a near stoichiometric AFR and decrease as the fuel mixture approaches lean or rich conditions. The λ values of the aromatic test fuels were lower than 1.0 (Fig. 3), i.e., under fuel-rich conditions. In contrast, the λ values of the reference fuel were close to 1.0, which lead to high NO_x emissions. This may be one of the reasons why NO_x emissions decreased compared to the RF when using low aromatic content fuel.

In brief, observations of the effects of gasoline aromatic content on criteria emissions in the test motorcycle show that a reduction in fuel aromatic content may lower THC and NO_x emissions, but NO_x was also influenced by the excess air ratio (λ). The λ appeared to be more important than fuel composition in the case of CO emissions for the test motorcycle. These findings agree with those of previous studies conducted on cars (Goodfellow *et al.*, 1996; MacKinven and Hublin, 1996; Zervas *et al.*, 2003).

Effects on Benzene Emissions

It has been evidently that aromatic content of gasoline may affect on benzene emissions from vehicle (McArragher *et al.*, 1996; Zervas *et al.*, 1999; Prati *et al.*, 2000). These emission factors from various test fuels (i.e., A15, A25, and A50) were applied to evaluate the effects of fuel aromatic content on benzene emissions. Analysis of fuel effects was carried out by calculating the emission variance in benzene emission for the aromatic fuels as compared to the A50.

The highest benzene emission factor appeared in A50; the value was 50.0 mg/km, which was followed by A25 (15.8 mg/km), and A15 (10.4 mg/km). A decrease in aromatic content from 50 vol% to 25 and 15 vol% showed a dramatic reduction in benzene emission by 68% and 79%, respectively. Many researchers have reported aromatics in fuel are the main precursors of exhaust benzene in cars (Petit and Montagne, 1993; McArragher *et al.*, 1999). Decreasing aromatics content reduces benzene in vehicle exhaust emissions because larger aromatic molecules are partly converted to benzene during combustion by dealkylation (Petit and Montagne, 1993; Goodfellow *et al.*, 1996; McArragher *et al.*, 1999; Jain *et al.*, 2004). The correlation results show a very strong correlation ($r > 0.99$) between benzene emission and the aromatics and benzene contents in fuel (Table 3). The result of correlation coefficient gives evidence for above discussions, i.e., exhaust benzene emissions were related to fuel aromatics and benzene contents. These results show clearly that benzene emission from motorcycle was influenced significantly by both benzene and aromatic content in the test fuel.

Comparison of the Effects on Motorcycles and Passenger Cars

Table 4 summarizes the effects of aromatic fuel contents on motorcycle exhaust emissions. Data on cars is also included for comparison. The fuel supply system and emission control system for the vehicle in the literatures are same as the test motorcycle, i.e., carburetor and no emission control system. Our findings are consistent with pervious studies which showed that the reduction of aromatic content in gasoline may reduce THC and NO_x emissions in carburetor engines without catalyst (MacKinven and Hublin, 1996; Prati *et al.*, 2000; Schifter *et al.*, 2004). The results of benzene emissions are also showed the consistency with pervious studies (Prati *et al.*, 2000; Schifter *et al.*, 2004). Above all, reduction of aromatic content in gasoline may reduce emissions of THC, NO_x, and benzene, except CO, in catalyst free carburetor engines regardless car and motorcycle.

Limitations

This research has shown an experimental approach where a series of fuels with various aromatic contents are tested on a four-stroke carburetor motorcycle and wide range of aromatic contents are included in the analysis. This approach can be applied in the studies related to fuel compositions and exhaust emissions to different motorcycles with different characteristics such as: displacement, engine type, and accumulated mileage. However, some limitations should be noted in this study. Only one four-stroke carburetor motorcycle was tested in this study and was given small dataset, although it is representative. In order to assess statistical significance of results and provides better representative results, it is recommended that the large sample size is needed by considering the affordable cost.

CONCLUSIONS

This study investigated the influence of fuel aromatic content on air pollutant emissions from a four-stroke motorcycle. Three aromatic fuels containing 15 (A15), 25 (A25), and 50% (A50) aromatics by volume mixed with gasoline were designed to evaluate the impact of fuel composition on criteria pollutant (CO, THC, NO_x) emissions. A new four-stroke carburetor motorcycle engine with a displacement of 125 cm^3 and without a catalytic converter was used in the experiments.

In general, lower aromatic content (25 and 15 vol%) gasoline produced more than 10% less THC and NO_x emissions than the reference fuel (aromatic content 30 vol%). CO emissions, on the other hand, did not appear to be related to the aromatic content of gasoline. A15 (15 vol% aromatics in fuel) showed the lowest criteria pollutant emissions among all aromatic-content test fuels. The reductions were 17 and 18% for THC and NO_x, respectively, compared to the RF, but CO emissions were only slightly reduced (2%). The λ values of the aromatic test fuels were lower than 1.0, i.e., under fuel-rich conditions, CO emissions were increased due to the lack of oxygen. This may be the reason why no reduction in CO emissions was observed when compared with the RF in this study. These results imply that lambda (λ) is more important than fuel composition for CO emissions in carburetor motorcycles without any engine adjustment. In addition to the influence of AFR, other fuel compositions

Table 4. Summary of effects of aromatic content on the vehicle emissions.

Test vehicle	Aromatics (vol%)	Effect on pollutant emission				Reference
		CO	THC	NO_x	Benzene	
New four-stroke motorcycle, w/o catalyst	50 → 25 50 → 15	▲ (2%) ▼ (6%)	▼ (2%) ▼ (7%)	▼ (5%) ▼ (5%)	▼ (68%) ▼ (79%)	This study
In-use two-stroke carburetor motorcycles, w/o catalyst	33 → 28	▼	▼	▲	▼ (23-26%)	Prati *et al.*, 2000
In-use carburetor cars, w/o catalyst	40 → 25	▼	▼	▼	--	MacKinven and Hublin, 1996
In-use carburetor cars, w/o catalyst	40 → 20	▲ (5%)	▼ (2%)	▼ (10%)	▼	Schifter *et al.*, 2004

▲: increase, ▼: reduction, ---: data not measured or not available, mix: the effects were inconsistent with regard to different tested vehicles or engine conditions, ( ): emission variance (%).

may also influence exhaust THC and NO_x emissions. The paraffin and naphthene contents may also influence the THC and NO_x emissions from the results of correlation coefficient, the CO emissions only depended on the fuel oxygen content in our study. In addition to criteria air pollutant, lowing fuel benzene decreased exhaust benzene was observed in our study. Benzene emission was mainly related with aromatic and benzene content in the fuel.

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