Journal of Hazardous Materials A123 (2005) 29–34

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

Influence of ethanol–gasoline blended fuel on emission characteristics from a four-stroke motorcycle engine

Li-Wei Jia [a], Mei-Qing Shen [a,*], Jun Wang [a], Man-Qun Lin [b]

[a] *Key Laboratory for Green Chemical Technology of State Education Ministry, School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, PR China*

[b] *Tianjin Motorcycle Technical Center, Tianjin 300072, PR China*

Received 4 November 2004; received in revised form 12 February 2005; accepted 22 March 2005

Available online 31 May 2005

Abstract

Emission characteristics from a four-stroke motorcycle engine using 10% (v/v) ethanol–gasoline blended fuel (E10) were investigated at different driving modes on the chassis dynamometers. The results indicate that CO and HC emissions in the engine exhaust are lower with the operation of E10 as compared to the use of unleaded gasoline, whereas the effect of ethanol on NO_X emission is not significant. Furthermore, species of both unburned hydrocarbons and their ramifications were analyzed by the combination of gas chromatography/mass spectrometry (GC/MS) and gas chromatography/flame ionization detection (GC/FID). This analysis shows that aromatic compounds (benzene, toluene, xylene isomers (*o*-xylene, *m*-xylene and *p*-xylene), ethyltoluene isomers (*o*-ethyltoluene, *m*-ethyltoluene and *p*-ethyltoluene) and trimethylbenzene isomers (1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene)) and fatty group ones (ethylene, methane, acetaldehyde, ethanol, butene, pentane and hexane) are major compounds in motorcycle engine exhaust. It is found that the E10-fueled motorcycle engine produces more ethylene, acetaldehyde and ethanol emissions than unleaded gasoline engine does. The no significant reduction of aromatics is observed in the case of ethanol–gasoline blended fuel. The ethanol–gasoline blended fuel can somewhat improve emissions of the rest species.

Keywords: Emissions; Motorcycle; Ethanol–gasoline blended fuels; Species

1. Introduction

In China, the estimative number of motorcycles will range from 95 to 100 million until the year of 2005; so, emissions of pollutants from motorcycle engines into the atmosphere are becoming a more and more concern. Now, the application of alternative fuels is one of means to lessen these pollutant emissions from motorcycle engines.

Alternative fuels, as defined by the Energy Policy Act of 1992 (EPACT, US), include ethanol, natural gas, hydrogen, biodiesel, electricity, methanol and so on. These fuels are being used worldwide in a variety of vehicle applications. They are a major force in the effort to reduce petroleum consumption, harmful pollutants and exhaust emissions in the transportation sectors.

Among alternative fuels, ethanol is one of fuels employed most widely. The reasons are in the followings. First, it can be produced from “cellulosic biomass”, such as trees and grasses and is called bioethanol [1]. Secondly, ethanol (CH_3CH_2OH) is made up of a group of chemical compounds whose molecules contain a hydroxyl group, –OH, bonded to a carbon atom; so, the oxygen content of this fuel favors the further combustion of gasoline. Besides, ethanol is most commonly used to increase gasoline’s octane number. It can be concluded that using ethanol–gasoline blended fuels can ease off the air pollution and the depletion of petroleum fuels simultaneously. As a result, studying the effect of ethanol fuel on the pollutant emissions and

* Corresponding author. Tel.: +86 22 278 923 01; fax: +86 22 278 923 01.
E-mail addresses: jlw2001@hotmail.com (L.-W. Jia), mqshen@tju.edu.cn (M.-Q. Shen).

0304-3894/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2005.03.046

performance of an engine holds many researchers' [2–6] interests.

Hsieha et al. [7] tested the properties of ethanol–gasoline blended fuels with various blended rates (0, 5, 10, 20, 30%) by volume. Results show that with increasing the ethanol content, the heating value of the blended fuels is decreased, while the octane number of the blended fuels increases. At the same time, the effect of the above ethanol–containing fuels on the exhaust emissions from a SI engine was studied, too. The engine test indicated that CO and total hydrocarbon (THC) emissions decrease dramatically as a result of the leaning effect caused by the addition of ethanol. The study of He et al. [8] pointed out that the fuel containing 30% ethanol by volume can drastically reduce engine-out THC, CO and NO_X emissions at idle speed, but unburned ethanol and acetaldehyde emissions increase. Hasan [9] investigated that using an ethanol–unleaded gasoline blend leads to a significant reduction in exhaust emissions by about 46.5 and 24.3% of the mean average values of CO and THC emissions, respectively, for all engine speeds. On the other hand, CO_2 emission increases by about 7.5%. The research of Ajava et al. [10] showed that the exhaust gas temperature, lubricating oil temperature and exhaust emissions (CO and NO_X) are lower with operations on ethanol–diesel blends as compared to operation on diesel. In the study of Yüksel and Yüksel [11], with the use of a new carburetor designed, a phase separation problem in gasoline–ethanol mixtures can be solved but also the alcohol ratio in the total fuel is increased, which will be meaningful for ethanol to be used universally.

In previous literature, information about the emission level of low-weight hydrocarbons from vehicles using ethanol–gasoline blended fuels is usually reported as THC amount with a little further specification of the individual compound contributions to this amount. It is necessary to identify volatile unregulated components and to quantify their concentration levels, since some species emitted from engines utilizing ethanol blended gasoline fuels or unleaded gasoline may be toxic, and hence, pose health hazard to the public, though very low content. For motorcycle engines or other small gasoline engines (e.g., lawn mower engines), now few data are available for showing the effects of ethanol–blended gasoline on exhaust emissions, especially, concerning individual species. In this present study, the object is to gain insight into the effect of 10% (v/v) ethanol–gasoline blends on regulated emissions and volatile unregulated components from a four-stroke motorcycle engine.

2. Experimental

2.1. Fuels used

Two test fuels adopted were purchased from China National Petroleum Corporation (CNPC). One was unleaded gasoline without any oxygenated additives, which was used as a reference fuel and as a base fuel for the preparation of gasoline/alcohol blends and it is called hereinafter as "base". The other was ethanol blended gasoline fuel containing 10% ethanol (E10) by volume. The compositions of test fuels are described in Table 1.

Table 1
The compositions of test fuels

	Base	E10
Alkene (vol.%)	32.7	29.4
Benzene (vol.%)	2.3	2.1
Aromatic (vol.%)	24.5	22.1
Oxygen (wt.%)	0.12	3.4

2.2. Equipment and analysis procedure

A new four-stroke motorcycle, HONDA CG125, was chosen as test one without catalytic converters. Table 2 presents the main properties of the engine of this motorcycle. In this experiment, the chassis dynamometer (AVL 20 in. Motorcycle) used is located in Tianjin Motorcycle Technical Center, China. The testing was performed on this chassis dynamometer according to European driving cycle (ECE) 15 cycles. Two types of samples were analyzed in this study. One was measured for the entire cycle with constant volume sampling (CVS, CUSSONS, P1800/P1500). The other was collected for five representative steady-state modes including both the idle stage and four cruising stages, which were 15 $km\,h^{-1}$ under the first gear mode, 32 $km\,h^{-1}$ cruising stage under the second, 35 and 50 $km\,h^{-1}$ under the third, respectively. On this chassis dynamometer, the wheels of this test vehicle were supported by rollers that simulated actually driving conditions, while the driver followed a test cycle.

In this study, HC, CO and NO_X of sample for one entire cycle were measured by a flame ionization detector (FID), a non-dispersive infrared analyzer (NDIR) and a chemiluminescent detector (CLD), respectively.

The concentrations of HC, CO and NO_X for stable driving modes in the exhaust gases were measured on-line by the AVL-DIGAS 4000 LIGHT multiple exhaust analyzer with pre-calibration, which includes NDIR for HC and CO, as well as CLD for NO_X. CO, HC and NO_X emissions' concentrations are mean values of five repeatable measurements for each stable operating mode.

Table 2
General parameters of the test engine

Items	Parameters
Engine type	Monocylinder, four-stroke, air cooled
Displacement	124.0 ml
Compression ratio	9.0:1
Dimension ($L \times W \times H$)	335 mm × 475 mm × 435 mm
Bore X stroke	56.5 mm × 49.5 mm
Maximum torque	7.0 kW/8000 rpm
Rating power	7.0 kW/8000 rpm

Table 3
Analysis conditions

	GC–MS	GC–FID
Apparatus	Agilent GC6890-MS5973N	Agilent 6890
Column	HP-5, 50 m × 0.53 mm × 5 μm	HP-PLOT U, 30 m × 0.32 mm × 10 μm
Carrier gas	Helium	Helium
Flow	0.8 ml min^{-1}	1.0 ml min^{-1}
Injector mode	Splitless	Splitless
Injector temperature	250 °C	200 °C
Detector temperature	MS Quad: 150 °C, MS source: 250 °C	250 °C
Oven temperature	Intial: 40 °C for 3 min, 40–200 °C with 30 °C min^{-1} Final: 200 °C for 3 min	Intial: 30 °C for 5 min, 30–210 °C with 30 °C min^{-1} Final: 210 °C for 3 min
Scan range	15–500 μm	

The steps of performing hydrocarbon speciation for stable driving modes are described below. First, a check valve must be connected between a sampling bag and the exhaust pipe due to the pulsed characteristics of the engine before samples are collected. All ducts were heated by electrical tape so as to prevent the losses of hydrocarbon by condensation. The sampling equipment schematic diagram was similar to the work of Tsai et al. [12]. Next, after sampling, samples were immediately taken to the laboratory for hydrocarbon species analysis by the combination of gas chromatography/mass spectrometry (GC/MS) and gas chromatography/flame ionization detection (GC/FID). Analysis details are presented in Table 3. The concentrations of aromatic isomers in the exhaust emissions were analyzed by the GC/MS using deuterated benzene (C_6D_6) as the internal standard, while we measured the contents of the rest by means of the GC/FID through external standard methods.

3. Results and discussion

3.1. Emissions of regulated pollutants

The results of regulated pollutants for one entire test cycle (ECE15) and the different steady-driving modes are presented in Fig. 1 and Table 4, respectively. Based on the equations in previous literature [12], the data in Table 4 were derived from the individual corresponding concentrations.

Fig. 1 shows CO, HC and NO_X emissions for one entire cycle. We can see that CO emissions for base and E10 test fuels were 6.85 and 4.74 g/km. Namely, CO emission amount was decreased by about 30.8% for E10 fuel, compared to base fuel. This is due to improving the combustion process as a result of the oxygen content in ethanol fuels. From Fig. 1(b), it was observed that HC emission was 0.562 g/km, if motorcycle engine was fueled with unleaded gasoline, whereas HC emission was 0.384 g/km for blended ethanol fuel. This indicated the HC emission was reduced by nearly 31.7% for one whole cycle. This result can be also explained by the fact that oxygenated characteristic of ethanol in blend fuels is more effective in enhancing oxidation of hydrocarbons than that in air. NO_X emissions for one entire cycle were presented in Fig. 1(c). For base and E10 fuels, NO_X emission values were 0.368 and 0.345 g/km, respectively. The reduction of NO_X emissions was relatively smaller, about 5.9% for E10 fuel. In other words, the ethanol added to gasoline produces minor effect on the decrease of NO_X emissions.

Table 4 shows CO, HC and NO_X emissions for the five different driving modes. It was found that for both test fuels, the higher CO emissions, even up to about 865 mg/km, were observed at intermediate cruising speeds, whereas CO emissions were lower at the idle stage and 50 km h^{-1}. CO emissions, at idle stage and 50 km h^{-1}, were decreased by about 14.8 and 16.9% for E10 fuel, as compared to base fuel. It is meaning to address that at intermediate cruising stages, the influence of the ethanol addition on CO emissions was insignificant as shown in Table 4.

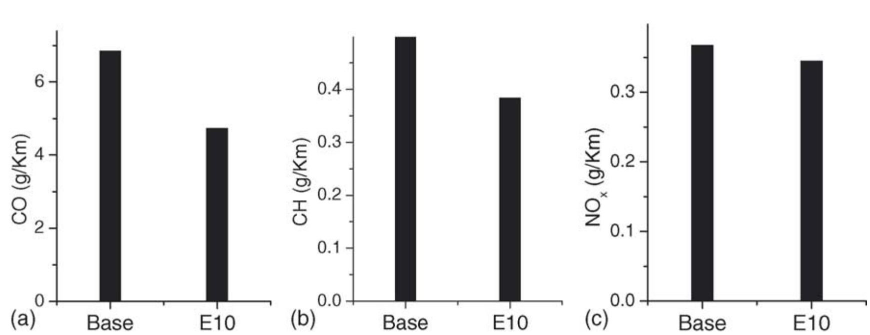

Fig. 1. Emissions of regulated pollutants for one entire test cycle.

Table 4
Mean values of regulated pollutants (in mg/km) for the different steady-driving modes[a]

	Idle stage[b]				$15\,km\,h^{-1}$ cruising stage				$32\,km\,h^{-1}$ cruising stage				$35\,km\,h^{-1}$ cruising stage				$50\,km\,h^{-1}$ cruising stage			
	Base		E10		Base		E10		Base		E10		Base		E10		Base		E10	
	MV	S.D.	MV	S.D.	MV	S.D.	MV	S.D.	MV	S.D.	MV	S.D.	MV	S.D.	MV	S.D.	MV	S.D.	MV	S.D.
CO	412	±8	351	±6	866	±15	830	±13	786	±11	761	±12	865	±16	861	±12	144	±3	120	±4
CH	40	2	24	±1	74	±3	68	±2	40	±2	42	±1	50	±3	46	±2	22	±1	14	±1
NO_X	8	<1	7	<1	21	±1	18	±1	25	±2	24	±1	27	±1	25	±1	70	±2	65	±1

[a] Given as mean value, MV; standard deviation, S.D.; $N = 5$.
[b] The unit of regulated compounds during idle stage is $mg\,min^{-1}$.

In the mass, from Table 4, it could be observed that HC emissions for E10 were reduced by nearly 40.0 and 36.4% at idle stage and high speed of $50\,km\,h^{-1}$, as compared to base fuel. For both fuels, HC emissions were higher at intermediate speeds, where no obvious influence of ethanol on the reduction of HC emissions was observed.

According to Table 4, for both fuels, it could be seen that at idle speed NO_X emissions were a lot lower than that at other modes; whereas at $50\,km\,h^{-1}$, remarkably high NO_X concentrations were observed, up to about 70 mg/km. The combustion process at idle speed can only produce a lower flame temperature and at high speed get a higher temperature, which are the reason of the above results. At the same driving mode, the addition of ethanol into gasoline did not influence NO_X emissions.

To sum up, for one entire test cycle, the effect of ethanol on the reduction of CO and HC emissions is significant. However, the ethanol fuel improves NO_X emission reduction lightly, even cannot. For five steady-driving stages, the decrease of CO and HC emissions are obvious at only idle and $50\,km\,h^{-1}$ stages, when E10 fuel is combusted.

3.2. Speciation of hydrocarbons

According to open literatures, many compounds were detected in the gasoline-fueled engine exhaust [13,14]. In this study, based on emission amount, the top-11 aromatic hydrocarbons detected were as follows: benzene, toluene, xylene isomers (*o*-xylene, *m*-xylene and *p*-xylene), ethyltoluene isomers (*o*-ethyltoluene, *m*-ethyltoluene and *p*-ethyltoluene) and trimethylbenzene isomers (1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene). It is declared that due to aromatic isomers MS being very similar (as an example, Fig. 2 presents MS of *o*-xylene and *p*-xylene), they have to be identified by the combination of their MS and retention time. The top-seven aliphatic ones detected were ethylene, methane, acetaldehyde, ethanol, pentane, butene and hexane. These hydrocarbon species are pollutants contaminating atmosphere. Fig. 3 presents hydrocarbon species emissions at different driving modes for two test fuels.

It could be seen from Fig. 3 that, among fatty compounds detected, at idle stage, methane emission concentrations in the case of E10 and base gasoline were, respectively, 0.95 and 1.60 mg/km. It is obvious that the ethanol in blend fuel favors combustion of methane, which was mainly produced by the decomposition of other long-chain hydrocarbons. In addition, butene, pentane and hexane emissions amount, at each driving mode (except $50\,km\,h^{-1}$ stage), were decreased to some extent, when E10 fuel was used. The effect of ethanol addition to gasoline on these fatty group compounds emission quantity distribution was similar at different driving modes (except $50\,km\,h^{-1}$ stage).

It is noteworthy for ethanol, acetaldehyde and ethylene emissions, when ethanol blend fuel was combusted in motorcycle engine. As is shown in Fig. 3, ethanol was not observed in the exhaust emissions for base fuel. Acetaldehyde emission increased slightly for the use of ethanol–gasoline blended fuels, since it may be produced through the partial oxidation of ethanol in E10 fuel. It is well known that humans develop irritation of the eyes, skin and the respiratory tract, when exposed to acetaldehyde vapors. Ethylene emission amount was higher for E10 fuel than that for base fuel at

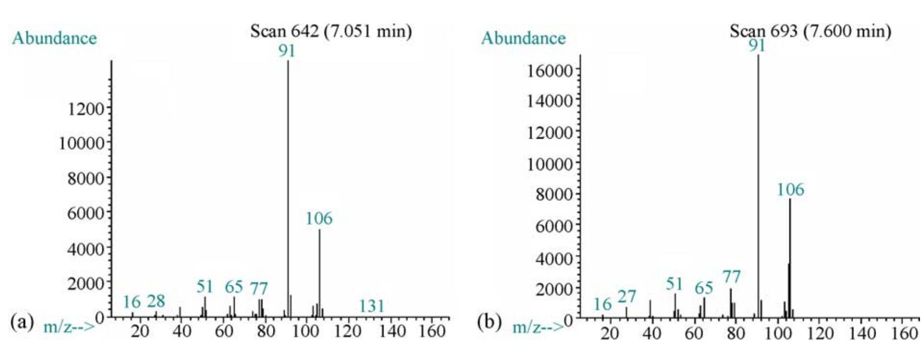

Fig. 2. Mass spectrometry of *o*-xylene (a) and *p*-xylene (b).

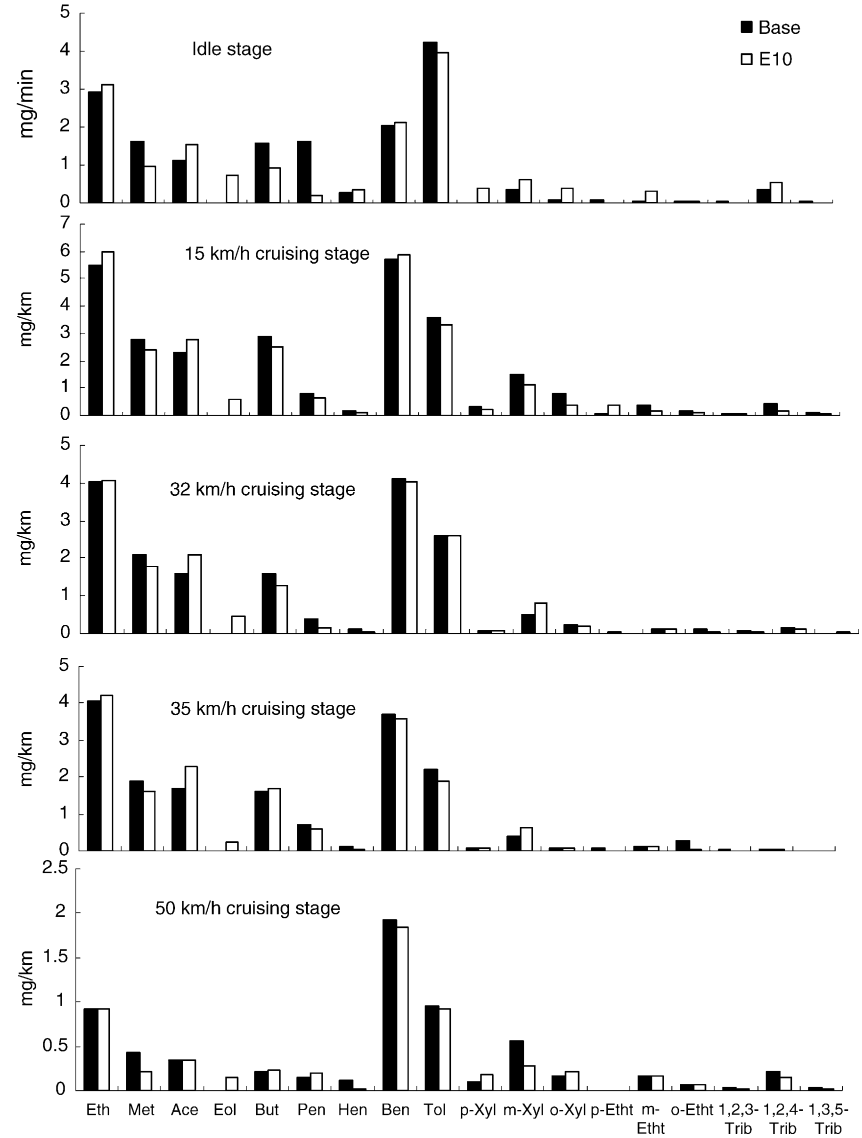

Fig. 3. Hydrocarbon species emissions of exhaust gas at different driving stages (Eth, ethylene; Met, methane; Ace, acetaldehyde; But, butene; Eol, ethanol; Pen, pentane; Hen, hexane; Ben, benzene; Tol, toluene; *p*-Xyl, *p*-xylene; *m*-Xyl, *m*-xylene; *o*-Xyl, *o*-xylene; *p*-Etht, *p*-ethyltoluene; *m*-Etht, *m*-ethyltoluene; *o*-Etht, *o*-ethyltoluene; 1,2,3-Trib, 1,2,3-trimethylbenzene; 1,2,4-Trib, 1,2,4-trimethylbenzene; 1,3,5-Trib, 1,3,5-trimethylbenzene).

different cruising stages. We can conclude that some ethylene may be formed through the dehydration process of ethanol, when the amount of alcohol in fuels is enough. Ethylene can cause breathing cardiac troubles and is one of the reasons for the formation of ozone [5]. In conclusion, the use of ethanol blend fuels cannot lessen toxic acetaldehyde and ethylene emissions.

Benzene and toluene, as aromatic carcinogenic compounds, which can cause harmful effects on the bone marrow and a decrease in red blood cells leading to anemia, were presented in great amount in motorcycle exhaust. At test-driving stages, benzene and toluene emissions were from 1.85 to 5.9 mg/km and from 0.92 to 4.2 mg/km for two test fuels. Compared for base fuel, benzene at idle stage was reduced by 2.4% for E10, whereas the reduction of HC emissions was nearly 31.7% at corresponding mode. This indicates that the effect of using ethanol–gasoline blend fuels on the benzene oxidation is comparatively poorer. This phenomenon was the same as that of toluene. Other aromatic emissions were relatively lower for these two fuels at all test-driving conditions. In sum, ethanol of E10 fuel plays insignificant effect on aromatic emissions, as compared to base gasoline.

4. Conclusions

From this study, the main results can be summarized below.

The ethanol addition to gasoline can improve emissions of regulated pollutants, such as CO and HC from motorcycle engine to some extend. The fluctuations of NO_X emissions are not remarkable, when E10 is used. Hydrocarbon species except ethanol, acetaldehyde and ethylene emissions are decreased somewhat from ethanol–gasoline blends-fueled motorcycle engine relative to gasoline-fueled motorcycle. Additionally, the effect of ethanol addition to gasoline on the improvement of aromatic emissions is not obvious.

For potential application to ethanol–gasoline-fueled vehicles, the extensions of this study are to undertake measures (such as prepare catalytic converters) for not only the control of HC and NO_X but also of hydrocarbon species, such as ethanol, acetaldehyde, aromatics and so on.

Acknowledgement

The authors are grateful to the National Basic Research Program (also called 973 Program) of China for its financial support (No. 2004CB719503).

References

[1] Z.Y. Hu, G.Q. Pu, F. Fang, C.T. Wang, Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission, Renew. Energ. 29 (2004) 2183–2192.
[2] R.D. Zhang, H. He, X.Y. Shi, C.B. Zhang, B.Q. He, J.X. Wang, Preparation and emission characteristics of ethanol–diesel fuel blends, J. Environ. Sci. 16 (2004) 793–796.
[3] M. Roger, N. Calle, A. Barbro, Emissions of aldehydes and ketones from a two-stroke engine using ethanol and ethanol–blended gasoline as fuel, Environ. Sci. Technol. 36 (2002) 1656–1664.
[4] Ö. Can, Ï. Celikten, N. Usta, Effects of ethanol addition on performance and emissions of a turbocharged indirect injection diesel engine running at different injection pressures, Energ. Convers. Manage. 45 (2004) 2429–2440.
[5] S.G. Poulopoulos, D.P. Samaras, C.J. Philippopoulos, Regulated and unregulated emissions from an internal combustion engine operating on ethanol–containing fuels, Atmos. Environ. 35 (2001) 4399–4406.
[6] E. Zerves, X. Montagne, J. Lahaye, Emission of alcohols and carbonyl compounds from a spark ignition engine: influence of fuel and air/fuel equivalence ratio, Environ. Sci. Technol. 36 (2002) 2414–2421.
[7] W.D. Hsieha, R.H. Chen, T.L. Wu, T.H. Lin, Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels, Atmos. Environ. 36 (2002) 403–410.
[8] B.Q. He, J.X. Wang, J.M. Hao, X.G. Yan, J.H. Xiao, A study on emission characteristics of an EFI engine with ethanol blended gasoline fuels, Atmos. Environ. 37 (2003) 949–957.
[9] M.A. Hasan, Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission, Energ. Convers. Manage. 24 (2003) 1547–1561.
[10] E.A. Ajava, B. Singhb, T.K. Bhattacharya, Experimental study of some performance parameters of a constant speed stationary diesel engine using ethanol–diesel blends as fuel, Biomass. Bioenerg. 17 (1999) 357–365.
[11] F. Yüksel, B. Yüksel, The use of ethanol–gasoline blend as a fuel in an SI engine, Renew. Energ. 29 (2004) 1181–1191.
[12] J.H. Tsai, H.L. Chang, Y.C. Hsu, H.C. Weng, C.Y. Yang, The speciation of volatile organic compounds (VOCs) from motorcycle engine exhuast at different driving modes, Atmos. Environ. 37 (2003) 2485–2496.
[13] F.H. Chang, T.C. Lin, C.J. Huang, H.R. Chao, T.Y. Chang, C.S. Lu, Emission characteristics of VOCS from athletic tracks, J. Hazard. Mater. A. 70 (1999) 1–20.
[14] R.H. Chao, T.H. Lin, T.L. Wu, Emission characteristics of VOCs in the exhaust of a gasoline-powered engine using additives, J. Aerosol. Sci. 28 (1997) S53–S54.