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Engine performance and emission characteristics of in-Vietnam motorcycles using biogasoline E10

[1]Anh Tuan Hoang, [1]Van Vang Le, [1]Van Huong Dong, [2]Quang Vinh Tran

[1]Faculty of Mechanical Engineering, Ho Chi Minh University of Transport, Ho Chi Minh city, Vietnam.
[2]School of Transportation Engineering, Hanoi University of Science and Technology, Ha Noi, Vietnam.

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Address For Correspondence:
Anh Tuan Hoang, Faculty of Mechanical Engineering, Ho Chi Minh University of Transport, No.2, D3 Road, Ward 25, Binh Thanh District, Ho Chi Minh city, Vietnam.
Tel: +84-904-317-584; E-mail: anhtuanhoang1980@gmail.com

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ABSTRACT

Vietnam is a developing country with the rate of motorcycle quantity and population in Vietnam considered as the biggest one in the world. Hence, the motorcycle emissions, themselves, are polluting the air and reducing the environmental quality effecting directly people's lives. However, with great potential for raw materials used to produce biofuels, Vietnam has implemented the policy to develop and provide a roadmap to use biofuels in the near future. Biogasoline E5 (5% ethanol, 95% gasoline) has officially been put on the market and bought to replace RON 92, RON 95 since 2015. After having some initial difficulties so far E5 have obtained the positive response from consumers. According to the approved schedule, in the next few years, the ethanol rate will continue to be increased the percentage to 10% ethanol (10% ethanol, 90% gasoline). Therefore, study of using bio-gasoline E10 for vehicles, especially motorcycle with a large number is very necessary. This paper presents the experimental study results of technical features, fuel economy and emissions of the motorcycle when using E10. The experiment results on Wave 110 RSX running with E10 and RON92 show that, while using E10 as fuel, HC emission is reduced 45.5%, CO is reduced 10.2%, engine power increases about 7% and fuel consumption decreases about 4%, however, NO_x emission increases about 37.1% and CO_2 increases about 7.2% in comparison with traditional RON92. The paper results will contribute to reduce the dependence on fossil fuel, be a proof in increasing the mixture rate of biofuels into fossil fuel, improve the emission characteristics of motorcycles and the condition of Vietnamese environment pollution.

KEYWORDS: Biogasoline; Ethanol; Biofuel; Fuel economy; Emissions.

INTRODUCTION

Demand of searching the new energy sources has appeared for a long time as fossil fuels are depleted very fast. In the introduced-new-energy source, biofuels (mainly biogasoline and biodiesel) are considered the most feasible, biofuels can compete with fossil fuels. Up to the present time, there are more than 64 countries have applied to use the route for using ethanol as the fuel for vehicles, in the world [1]. Figure 1 shows the ethanol production in the worldwide in recent years [2]. In 2015, all countries in the world has produced a total of 115.6 billion liters of ethanol, of which the US accounted for over 50% with 66.6 billion liters [2]. Earlier, in 2014, all countries in the world has consumed a total of about 100 billion liters of ethanol, of which about 87% used as fuel.

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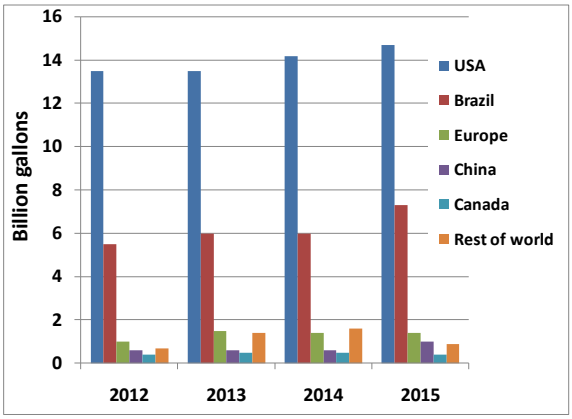

Fig. 1: Global ethanol production [2]

This rate has increased sharply as compared to nearly 74 billion liters of ethanol used as fuel in 2009. The International Energy Agency (IEA) has predicted that the consumption of biofuels in 2025 will be approximately 400 billion liters, get about 8% of the total fuel consumption of the vehicle [1].

The leading countries in the production and consumption of ethanol in the world are the USA, Brazil and the EU, which are consuming about 80% of total world consumption. USA has set a target to use 164 billion liters of ethanol per year for blending with gasoline by 2022. Consumption of ethanol in key markets such as Brazil and the USA with annual growth around 10%. In that time, the EU also set a target in 2020, all member states must replace 10% of fuel used for vehicles by renewable fuels such as ethanol. Even, Northern Europe countries also set higher targets aiming at eliminating completely fossil fuels in 2030 [2]. In Asia, some countries have also set a target for using biofuels, for instance, China will force the vehicles to use E10 by 2020. Thailand also aims that biofuels will account about 20% of total fuel consumption by 2018 [1]. Studies on the use of biogasoline show that, when the engine convert from using fossil gasoline to biogasoline, the engine power, torque can be improved a bit, but the fuel consumption rate increases. Specifically, when tested 4-cylinder engine, electronic fuel injection with E10, at full load, the engine power and fuel consumption increase compared to traditional gasoline [3]. This is explained that the oxygen presence in the ethanol molecular supports to improve the combustion progree and increases engine power. However, the heating value of biogasoline is lower hence fuel consumption rate is higher than that of fossil gasoline. In another study, M. Al-Hasanva et al [4] has conducted a test on 4-cylinder gasoline engine, the compression ratio of 9: 1 with the biogasoline sample rates ranging from 0% to 25% of ethanol, at 1000 - 4000 rpm of speed and 75% of throttle. The study results denoted that, the technical features of the engine was improved when running on biogasoline. Furthermore, while the proportion of ethanol was increased, the equivalent air ratio was reduced, i.e the mixture tended to fade. In terms of emissions, the published study results also were presented a significant reduction in HC and CO emissions, but increase in CO_2 emissions when using biogasoline for the engine. Particularly, the quite different results announced on NOx emissions [4-8]. These are also explained due to mentioned advantages of biogasoline help to improve the process of burning mixture.

In Vietnam, the basis studies aiming at giving the roadmap and using biogasoline E5, the in-country researchers also gave some noticeable results. Some studies of using E5 on gasoline engine [9] gave the positive results and the agreement on the economic, technical, emission indicators. However, the results requiried a long time for runing engines as durability and longevity of the engine is also quite limited and not been clearly confirmed. Comparative test results on the motorcycle using carburetors with fossil gasoline (RON92) and biogasoline E5 showed that, the engine power increased by about 6.5%, fuel consumption decreased by 6.4% when using E5 as fuel [7]. In terms of emissions, the components CO and HC emissions decreased 14.4% and 21.6% respectively when using E5 instead of fossil gasoline. However, the NO_x and CO_2 emissions in the case of using E5 is higher than that of traditional gasoline. This result is a clear demonstration of the in-engine improved combustion, temperature in the combustion increases and results in the amount of NO_x, burning more completelety so increasing CO_2 emission.

Many researchers carried out the experiment about using blend of ethanol and traditional gasoline in spark ignition (SI) engines. The resuts showed that, the engine power increases up to 50% while using E20, E40, E60, E80 and E100 on SI enginethe with four strokes. Besides, the (CO) and the (HC) emissions are proportional and inversly and the CO_2 emission is proportional to the increase in percentrage of ethanol in the blends. These results is due to the combustion improvement [11]. Other study showed that the increase in power of an SI engine fueled with E5 and E10 by 2.2% and 1.1%, the increase in fuel consumption by 5.2% and 5.5% respectively in comparison with gasoline [12], 6% of ethanol in blend with gasoline gave a better performance in comparison with 12% of ethanol [13]. Furthermore, some SI engine modifications to run with

blend of bioethanol and gasoline such as the increase in compression ratio were suggested [14]. The other results such as the improvement of pollutant emissions, the combustion efficiency due to oxygen component, engine performance as a four-stroke motorcycle with carburetor fueled with E3, E5, E10, E15, E20, E25, E30 are shown [15].

According to the schedule approved by Decision of the Vietnamese Prime Minister, at the end of 2017, biogasoline at a rate of 10% ethanol (E10) will be used as fuel for road vehicles in nationwide. the number of motorcycles in Vietnam shown in Fig.2 is the fourth country in the world. Currently, five major motorcycle manufacturers in Vietnam include Honda, Yamaha, Piaggio, Suzuki and SYM, which sold out the market a dozen of different type of motorcycles.

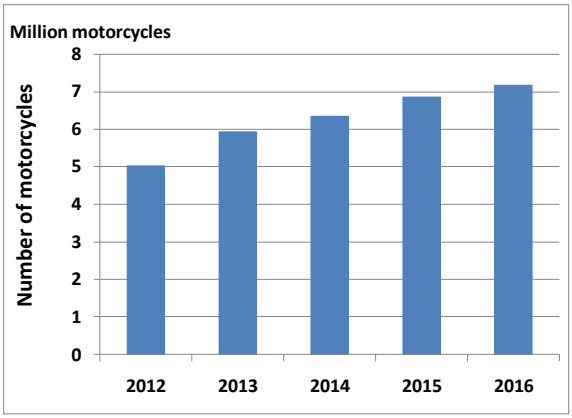

Fig. 2: Number of motorcycles in Vietnam from 2012-2016

Figure 2 shows that, by the end of 2016, 3.121.023 of motorcycles was sold and more 9.5% compared to 2015. Therefore, the total of motorcycles in Vietnam is 7.175.809. Therefore, research using E10 biogasoline for vehicles, especially motorcycle with a huge number is very necessary and a urgent task. This paper presents the results of empirical research about technical features, fuel economy and emissions characteristics of the motorcycle when engine is fueled with fossil gasoline and E10 biogasoline. The measurements on the dynamometer with modern equipment aiming at ensuring the accuracy and reliability of the research results are carried out. From the obtained results, the authors have made the recommendations for the user of vehicles in the near future.

MATERIALS AND METHODS

2.1. Material:

Biogasoline is created by mixing anhydrous ethanol with traditional gasoline in a certain proportion, E10 contains 10% of ethanol. Ethanol is mixed with gasoline and considered as a fuel additive that is blended into gasoline instead of lead additives. Lead, ethanol or other additives are mixed into gasoline to increase octane and help the engine better operation, more durable. Bioethanol with the chemical formula C_2H_5OH are processed through fermentation of organic products such as starch, cellulose, lignocelluloses or grains such as corn, wheat, soybeans or bark, bagasse... Vietnam is an agricultural country, the agricultural products are plentiful. Vietnam has a variety of materials that can be used for ethanol processing. They are classified as four potential groups: Sugars and starches (rice, corn, sugarcane, cassava); "Wood" contains cellulose (perennial plants, waste of wood processing); Agricultural residues (straw, waste after sugarcane harvest and maize, cassava body; bagasse); Others (organic waste components; cellulose grasses; algae). In Vietnam, E10 is produced mainly by cassava through alcoholic formation with enzyme and shown in the reaction:

(Cellulose) $2(C_6H_{10}O_5)_n + nH_2O \rightarrow$ (Glucose) $2nC_{12}H_{22}O_{11}$; by amylase enzyme

(Glucose) $C_{12}H_{22}O_{11} + H_2O \rightarrow$ (Glucose) $C_6H_{12}O_6$ + (Fructose) $C_6H_{12}O_6$; by mantaza enzyme

(Fructose) $C_6H_{12}O_6 \rightarrow$ (Ethanol) $2C_2H_5OH + 2CO_2$; by zimaza enzyme.

Cassava is easy to plant, less requirement in land, less investment, suitable for different ecological zones and household economic conditions. Vietnam, natural and climatic conditions are suitable for growth and development of cassava, even cassava is mainly grown on sandy soils, rocky soils, and sloping land and over 4 ecological regions of Vietnam such as the Midlands of Northern mountainous areas, Northern Middle, and

Southern East. Cassava area ranks the third after rice and maize with 560.000 hectares. Under the plan of the cassava development from 2011 to 2020 and the orientation to 2025, if Vietnam does not export the dry cassava, basically, the supplied cassava will meet the demand of the ethanol factories. In 2015, the cassava productivity has averaged 18.3 tons per hectare, higher than the world average of 12.2 tons per hectare but still lower than planned and much lower than the productivity of some countries in the area such as Thailand (22.34 tons/ha), India (35.11 tons/ha). Output of about 650 million liters of ethanol will be equivalent to the total capacity of existing plants. Raising the total capacity by 2025 to 1.000 million liters per year will result in being short of about 2.2 to 2.5 million tons of fresh cassava. On 7/01/2017, Vietnam will stop selling RON 95 and RON 92 and replace them by E5. Although, E10 will be compulsory for selling and using for motorcycle by 2020, however, currently, raw material is not satisfying the requirement in productivity for manufacturing bioethanol. Therefore, Vietnamese government is studying to carry out the policy in order to maintain and develop sustainably the raw material aiming at manufacturing bioethanol.

Some advantages of bioethanol are renewable fuel, reduction in petroleum imports, improvement of the payment balance, energy security, reduction the demands and the dependence on fossil fuels. Furthermore, some researchers also showed that, bioethanol could promote the development of agriculture and the incomes of producers and farmers, especially with a agricultural as Vietnam. In term of chemical and physical properties, bioethanol has many characterized advantages such as high octane number [16], higher latent heat [17], 34.7% of oxygen in the molecular assisting the combustion process more completely [18], cleaner emissions and thus engine thermal efficiency and increased torque [19,20], the evaporative emissions due to lower vapor pressure [21]. Bioethanol has high laminar flame propagation speed, which makes combustion process to be finished earlier and broadens its flammability limit [22], non of knocking from gasoline engine with indirect injection although high compression ratio [23], easily mixable in gasoline [24], lower toxic emission than fossil gasoline. However, some disadvantages of bioethanol are considered as lower energy [25], appearance of aldehydes and difficulty in starting cold due to lower vapor pressure [26], enhancement the corrosion on ferrous materials [27], triatomic molecule resulting in lower combustion gas temperature otherwise higher gas heat capacity [28]. Properties of pure bioethanol, E10 and RON 92 available in Vietnam are given in Table 1.

Table 1: Properties of E100, E10 and RON 92 in comparison with Vietnamese standard 6776:2005

Properties	RON 92	E100	E10	Vietnamese standard 6776:2005 [10]
Research Octane Number (RON)	92.4	109.2	94.4	≥ 92
Reid vapor pressure, kPa	60.5	17	59.4	43-75
Aromatic hydrocarbon content, %volume	31.6	0	27.8	≤ 40
Distillation temperature, ^oC				
Initial boiling point	38.9	78	41.6	-
10%, ^oC	53.6	78	51.0	70
50%, ^oC	93.6	78	73.8	120
90%, ^oC	158.6	79	161.6	190
End boiling point	180.0	79	185.5	215
Sulfur content, %weight	0.0063	0	0.0055	-
Oxygent content, % mass	0	34.7	3.93	≥ 2.7
Density at 15^oC, kg/m^3	732	790	740	-
Lower heating value, MJ/kg	44	26.9	37	≥ 36

It can be seen from Table 1 that:

- Lower heating value of E10 is about 16% lower than that of RON 92
- E10 with 3.93% of oxygen content in molecular may promote the combustion more complete and result in higher exhaust gas temperature.
- E10 with lower aromatic hydrocarbons and sulfur content will reduce the toxic emission.

2.2. Methods:

Selected test subjects were a motorcycle of Honda Wave 110 RSX with the main parameters given in Table 2. The reason for choosing this vehicle is the common model motorcycle, which is very widely used in the Vietnamese market. As announced by Vietnamese Honda, cumulative sales of this motorcycle had risen up 4.3 million by beginning of 2017.

Table 2: Main parameters of test motorcycle

Description	Parameters
Type of motorcycle	Honda Wave 110 RSX
Type of engine	Gasoline, 4 strokes, 1 cylinder, air cooled
Cylinder volume	109.1cm^3
Bore/Stroke	50mm x 55.6mm
Compressed ratio	9:1
Maximum power	6.18kW at 7500rpm
Maximum torque	8.65Nm at 5500rpm
Fuel system	Carburetors
Volume of lubricating oil	1 liter
Volume of gasoline tank	3.7 liter
Length x Width x Height	1919mm x 709mm x 1080mm
Body weight	100kg

The comparative experiments have carried out on the same motorcycle used two kinds of fuel, biogasoline E10 and RON92 fuel available on the market. E10 fuel used in this study meets the technical requirements in the National Technical Regulation on gasoline, diesel fuels and biofuels that are effective from 01.01.2016 [10]. When test engine runs with each type of fuels, the engine power and fuel consumption according to the speed curve will be measured, at the 3rd gear and the 4th gear and 100% of accelerator pedal. Measuring speed range is from 20-80 km/h, step 10 km/h. The test for measuring emissions was conducted according to the Vietnamese standard 7357: 2010 (equivalent to EURO II standards). The schematic of experimental setup for Wave 110 RSX test is shown in Figure 3.

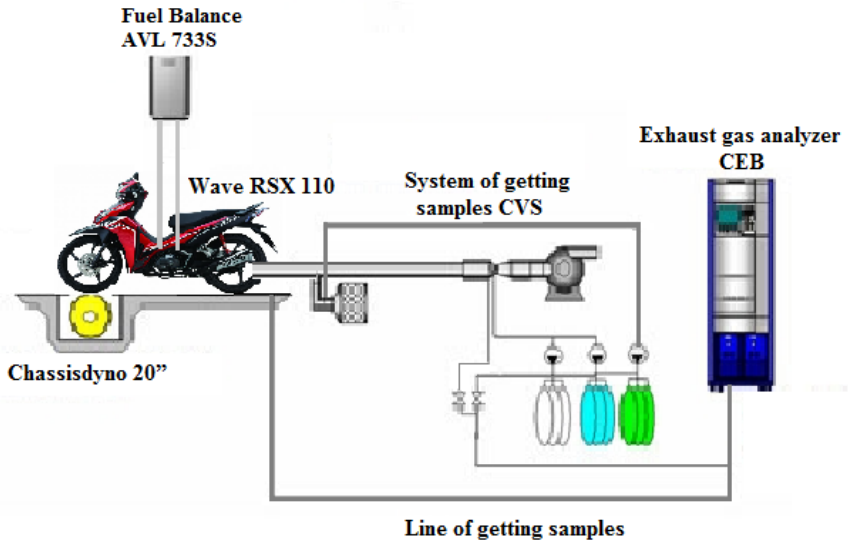

Fig. 3: Schematic of experimental setup for Wave 110 RSX test

In this measurement, the selected test cycle is ECE R40 cycle, with a total time for test is 1220 seconds, distance test is 6 km with 50 km/h of maximum speed. All experiments in this study were performed in the laboratory of combustion engines. Motorcycle is placed on a dynamometer Chassisdyno 20" formed rollers to measure the engine speed and power. This dynamometer is connected with emissions testing system to take the measurement results related to emission concentration of hazardous substances. All of testing equipment is provided synchronously by AVL, Austria.

RESULTS AND DISCUSSION

3.1 Power:

The power of Honda Wave 110 RSX at the 3rd gear and the 4th gear are shown in Figure 4 and Figure 5.

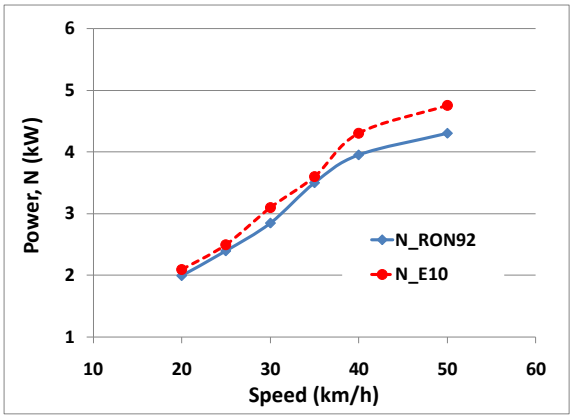

Fig. 4: Power at the 3rd gear

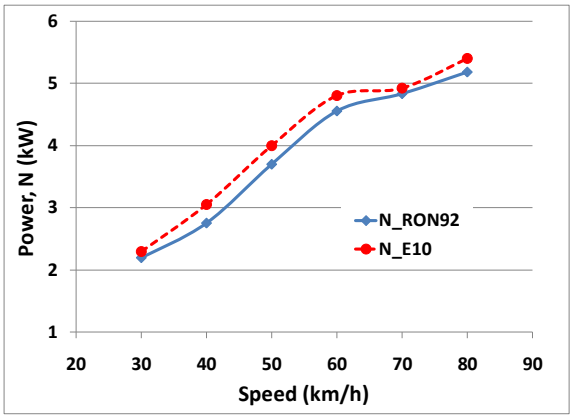

Fig. 5: Power at the 4th gear

From Figure 4 and Figure 5, it can be seen that the Wave 110 RSX 's performance is improved in all speed at the 3rd gear and the 4th gear when using E10 instead of fossil gasoline RON92. At the 3rd gear, the maximum difference in power is 10.46% at 50 km/h and the minimum difference in power is 2.85% at 35 km/h. However, at the 4th gear, the maximum difference in power is 10.90% at 40 km/h and the minimum difference in power is 1.86% at 70 km/h. The average increase in power on the speed range at the 3rd gear is 6.87% and at the 4th gear is 6.59%. Thus, improved power level as using E10 at the 4th gear is smaller than that of the 3rd gear. The improvement performance when using E10 can be explained that E10 is more volatile because certain amount of available oxygen in the fuel helps the better evaporation process and mixture, the combustion happens faster and more efficiently.

A more detailed review on each gear and it can be seen the difference in improved trends about the vehicle's performance. At the 3rd gear, in the low-speed (under 35 km/h), the rate change of power is very little. However, when the speed is over 40 km/h, the level of power increase is higher and observed the clear difference. Meanwhile, at the 4th gear, the improved power trend goes in the opposite direction. The significant change in power is only observed at the medium speed (below 70 km/h), and when the vehicle speed increases, the rate of change in power decreases.

3.2 Fuel consumption:

Results about measured fuel consumption of Honda Wave 110 RSX at the 3rd gear and the 4th gear are shown in Figure 6 and Figure 7.

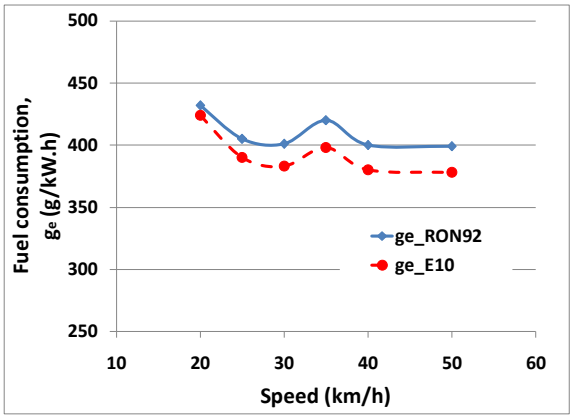

Fig. 6: Fuel consumption at the 3rd gear

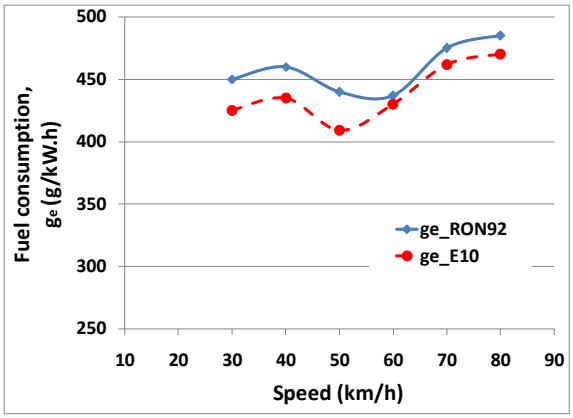

Fig. 7: Fuel consumption at the 4th gear

It can be seen that in all surveyed speed ranges, fuel consumption for E10 is lower than that of RON92, however there are different from decreased levels.Figure 6 shows that, at the 3rd gear and low-speed (under 35 km/h), the reduction in fuel consumption is around 3%, while in the higher speed, the fuel consumption reduction is about 4.7%. On average for the whole of speed range, at the 3rd gear, the fuel consumption rate as using E10 is 3.7%. The maximum E10 consumption is 424.18 (g/kW.h) at 20 km/h in comparison with 432.21 (g/kW.h) of RON 92 at the same speed, the minimum E10 consumption is 378.02 (g/kW.h) at 50 km/h in comparison with 399.14 (g/kW.h) of RON 92 at the same speed.

Figure 7 shows that, at the 4th gear, the reduction in fuel consumption is an opposite trend. At the low and medium speed (below 60 km/h), the reduction in fuel consumption as engine fueled with E10 is about 6.5% in comparison with RON92. However, at the higher speed, the reduction in fuel consumption is only about 3%. On average for the whole of speed range, at the 4th gear, fuel consumption when engine fueled with E10 is 4.4% lower than that of RON92. The maximum E10 consumption is 470.09 (g/kW.h) at 80 km/h in comparison with 485.16 (g/kW.h) of RON 92 at the same speed but the minimum E10 consumption is 409.18 (g/kW.h) at 50 km/h in comparison with 437.15 (g/kW.h) of RON 92 at 60 km/h.

Trends of fuel consumption change as using E10 on Figure 6 and Figure 7 are also consistent with the presented results of power measurement. Due to structure of fuel system is kept constantly (carburetor), so the supplied fuel mass at the survey mode is the same, when the engine power changes, the fuel consumption will also changes corresponding.

From the above test results about working features and fuel economy, it can be concluded that the E10 promotes the evaporation and combustion better than that of RON92. Although E10 calorific value is lower than that of RON92, because ethanol has a lower calorific value but with oxygen content in fuel and good evaporation so the difference in heating value of E10 have been offset by the fuel combustion more completely and thoroughly. Moreover, E10 with a higher octane value in comparison with RON92 results in a good resistance to detonation, thereby contributing to increase power and reduce fuel consumption.

3.3 Emissions:

The measurement results about the emissions of 110 Honda Wave RSX following ECE R40 test cycle are given in Table 3.

Table 3: Emissions of Honda Wave 110 RSX motorcycle based on ECE R40 cycle

Emission content (g/km)	RON 92	E10	EURO II standard
HC	0.694	0.378	1.2
NO_x	0.278	0.381	0.3
CO	4.582	4.116	5.5
CO_2	35.291	37.823	-
Fuel consumption (liter/100 km)	2.127	2.094	-

According to the results given in Table 3, when using E10 as fuel, HC emission is reduced 45.5%, CO is reduced 10.2% in comparison with traditional RON92. However, NO_x emission is 37.1% and CO_2 is 7.2% higher than those of traditional RON92. Fuel consumption per 100km reduces 1.6%. In comparison of emissions with EURO II standard, it can be found that, the NO_x emission for RON92 meets EURO II standards, but for E10 does not. Thus, if using E10 for motorcycles, it would require a little adjustment, such as changing the ignition angle to reduce the combustion temperature and result in lower NO_x emissions than the allowable value.

Above emission measurement results can also be explained that the better combustion process when using E10 results in reducing HC and CO emissions, and the fuel is burnt completely and the high temperature inside the cylinder leads to increase CO_2 and NO_x components.

Conclusions:

Alternative fuels and biofuels, which are renewable energy source, play an important part and become more and more necessary because of fossil fuel depletion and environmental pollution. Ethanol is considered as a full-potential alternative fuel used in many countries in the world. From the study results about evaluating the economic, technical features and emission characteristic when using fuel E10 for motorcycles, some conclusions are shown:

i) The physical and chemical properties of E10 such as octane number, distillation temperature, Reid vapor pressure, density are similar to those of RON 92. However, some notable characteristics of E10 are lower aromatic content, lower sulfur content but higher oxygen content in comparison with traditional RON 92.

ii) Engine power increases about 7% and fuel consumption decreases about 4% while using biogasoline E10 (10% of ethanol) as fuel. Motorcycle does not need to adjust the structure but it is ensured the steady work conditions on the whole of speed range.

iii) The degree of harmful ingredient emission such as HC and CO components when using E10 tends to reduce, otherwise CO_2 and NO_x components increase.

When using E10 as fuel, NO_x emissions do not meet the requirements under the current regulations (EURO II), therefore it is necessary to use some small adjustments to reduce these emission components. Nowadays, EURO VI is being applied in many countries in the world; therefore, at the side of the technology solutions, "biofuels" solutions are surely necessary to meet these EURO standards.

In next study, the issues related to durability, longevity of engines, the level of adapted machine part for this fuel will be carried out to offer a complete conclusion about the use of E10 on the vehicles. Moreover, the ever-increasing rate of ethanol such as E15, E20, E25, E30 is also considered using in motorcycles as well as the impact of oxygen component in ethanol to combustion and emission characteristic.

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