Performance and Emission Characteristics of Popular 4-Stroke Motorcycle Engine in Vietnam Fuelled with Biogasoline Compared with Fossil Gasoline

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Abstract— **Pollutant emission from motorcycles in Vietnam where is among the countries with the highest number of motorcycles is very serious problem. From the beginning of 2018, biogasoline E5 will be officially distributed nationwide, and in the next stage, biogasoline E10 will be used in 2019 to replace the as-used fossil gasoline. This work presents the results of empirical research about engine performance, and emission characteristics as using biogasoline E10 for the most popular motorcycle Honda Wave RX110 in Vietnam. As showed results, there are the increases in engine power, thermal efficiency, NOx and CO2 emissions, otherwise, the reduction of fuel consumption, CO emission, HC emission in comparison with E5 and fossil gasoline-RON95 are reported. This study result is the proof of confirmation about the benefits of in-using biogasoline, diversification of fuel sources and reduction of environmental pollution.**

Index Term— **biogasoline, biofuels, bioethanol, emission characteristic, engine performance, motorcycle**

I. Introduction

The sharp increase in the energy demand and the inability to replenish the limited energy sources such as fossil fuels were occurring, furthermore, the environmental pollution level were ever-increasing because the fossil fuel combustion certainly aggravated the global warming emergency, ever-depleting fossil fuels, and the crisis about energy in the world (Mohan, S.V et al, 2008). As reported, there were around 700 million of light duty vehicles and trucks, automobiles, and motorbikes over the world, and the number of these vehicles will be 1.3 billion by 2030, and 2 billion by 2050. The report of BP Statistical Review of World Energy showed the 1% of increase in the primary energy consumption of the global in 2016 (BP Statistical Review of World Energy, 2017). The International Energy Agency statistics also indicated that, about 60% of the total oil consumption in the world belongs to the transportation means. This energy consumption growth affected the stability of ecosystems and global climate as well as global oil reserves.

Fig.1 showed the bioethanol productivity in 2016 that increased 3% and 5% in comparison with 2015 and 2014, respectively. The countries with the most bioethanol production and most bioethanol consumption were USA, Brazil and the EU, where produced around 90% and consumed around 80% of bioethanol total consumption compared to the whole world.

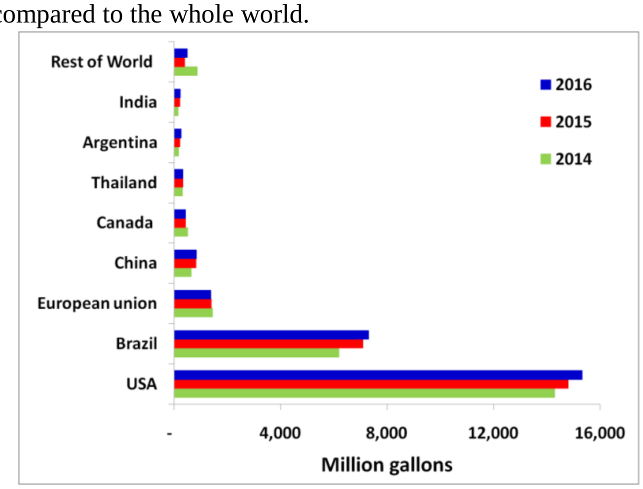

Fig. 1. Worldwide bioethanol production

There were 26.584 million gallons of total bioethanol produced by all countries in 2016 which 15.33 million gallons were produced in USA. In Brazil, more than 90% of new cars were equipped with bioethanol/biogasoline engines and aim to deliver 64 billion liters of green fuel by 2019. In Asia, the world's two most populous countries, India and China, the vehicles were also converted into using biogasiline E10 and E20. India Government has agreed on the principle of raising the rate of biofuels from 5% up to 20% since 2017. Meanwhile, biogasoline E10 were used extensively in 6 provinces and 27 cities and over the country in 2020, in China. Besides, using biogasoline based on assistance of the Thailand Government saved more than $1 billion per a year from the cancellation of the subsidy program for using both biogasoline and fossil gasoline. The International Energy Agency (IEA) anticipated around 400 billions of gallons of biogasoline consumption in 2025 correspondently to 8% in comparison with the total fuel consumption for the vehicles (BP Statistical Review of World Energy, 2017). In Vietnam, from 1 January 2018, only biogasoline E5 or RON95 was allowed and used in the market to contribute to ensuring the energy security, reducing the dependence on petroleum, improving the environment, and developing the sustainable agriculture. Based on the schedule, at the beginning of 2019, biogasoline E10 will be sold and compulsory for road vehicles in all provinces and cities. As reported, the number of in-Vietnam motorcycles was the fourth rating in the world with nearly 47 million by June 2017, and motorcycle was the primary cause of air pollution with 70% - 90% in the total of pollution source from transportation sectors (Hoang, A.T et al, 2017). The environmental pollution in Vietnam due to ever-increasing motorcycle number was a serious problem. Thus, study of using biogasoline E10 for in-Vietnam motorcycles was extremely necessary and urgent.

The most interesting property of bioethanol, which was considered as a fuel of SI engine, was renewable. Bioethanol was produced from many sources such as corn, cane, barley, cassava, maize, many types of agricultural and forestry residues or waste biomass (Mustafa, K et al, 2009; Shurooq, S et al, 2015). Many studies on using biogasoline showed a bit increase in engine power and fuel consumption rate in comparison with fossil gasoline (Hasan, A et al, 2017). A gasoline engine with four cylinder and 9: 1 of compression ratio in case of using biogasoline sample E0, E5, E10, E15, E20, E25, at speed from 1000rpm - 4000 rpm, and 75% of throttle was taken experience by M. Al-Hasan et al. (2003), and the improving of engine-technical parameters and features was denoted. Moreover, some advantages of bioethanol over fossil gasoline included carbon monoxide (CO), and unburned hydrocarbon (HC)-significant reduction, the better characteristics of anti-knock that allow for using, operating the engines with higher compression ratio also were reported (Ashraf, E, 2016), the increase in CO2 emission and the quite difference of NOx emission were announced (Hyun, K.N et al, 2017; Ojapah, M et al, 2014). Easily flammable and oxygenated characteristic supplied about 34.78% oxygen contained ethanol (C_2H_6O) apparently caused the CO emission reduction (Samuel, R.A et al, 2015). The transportation and storage issue for ethanol was safer than that of fossil gasoline because of low Reid evaporation pressure and higher flash point and temperature of auto-ignition (Enis, A et al, 2014). The 3–5 times higher of ethanol evaporation latent heat in comparison with gasoline provides lower losses of evaporation and temperature intake manifold and the increase in volumetric efficiency (Emad, S et al, 2013). On the other hand, the liquid property of ethanol made its storage and dispensing similar to fossil gasoline (Emad, S et al, 2013; Wen-Yinn, L et al, 2010). Moreover, ethanol was considers as an additive substituting MTBE (methyl tertiary butyl ether was a gasoline additive for octane number improving) in the future because of its characteristics such as unleaded, uncontaminated groundwater, unharmed human health (Yan, X et al, 2013; Maria, A.C et al, 2016). Besides, bioethanol showed many advantages about physicochemical properties compared to fossil gasoline such as high octane number, increase in thermal efficiency and torque of engine (Sebayang, A.H et al, 2017; Hsi, H.Y et al, 2012), workability with high compression ratio for indirect–injection-gasoline engine without knocking, easy blend with gasoline (Omar, I.A et al, 2018; Yung, C.Y et al, 2013). However, some bioethanol disadvantages such as lower energy, -CHO component containing, enhanceable material corrosion were reported by Hoang et al. (2017); Paolo et al. (2014).

In this work, the economic-technical features and emission characteristics of the motorcycle engine Honda Wave RX110 (the most popular motorcycle in Vietnam) fueled with E10 were measured experimentally, compared to fossil gasoline and biogasoline E5. As-obtained results proved the applicability of E10 for motorcycles in Vietnam where the people have been not much interesting, not high awareness about using biofuel and biogasoline.

II. MATERIALS AND METHODS

Nowadays, all of Vietnam's bioethanol production plants are using cassava as the main raw material. Bioethanol productivity has been meeting enough for mixing with fossil gasoline to produce biogasoline E10. The properties of E10 (10% of bioethanol and 90% of RON 95 gasoline) in comparison with RON 95 and E5 were given in Table I.

Table I
Properties of E100, E10 and RON 95

Properties	RON95	E100	E5	E10	Method
Density (kg/l at 15.5°C)	0.7575	0.79	0.7591	0.7608	ASTM D4052
Research Octane Number (RON)	95.4	109.3	96.7	98.1	ASTM D2699
Reid vapor pressure, kPa at 37.8°C	53.7	17	59.3	59.6	ASTM D5191
Distillation temperature, °C					ASTM D86
Initial boiling point, IBP	35.5	78	36.5	39.5	
10%, °C	54.5	78	49.7	54.8	
50%, °C	94.4	78	88.0	72.4	
90%, °C	167.3	79	167.7	159.3	
End boiling point, EBP	197.0	79	202.5	198.3	
Lower heating value, MJ/kg	44	27	40.2	41.1	ASTM D240
Laten heat of evaporation, kJ/kg	400	910	-	-	ASTM D6729
Stoichiometric air/fuel, weight	9	14.7	-	-	
Oxygent content, % wt	0	34.7	3.7	3.93	ASTM D4815

Table II showed primary parameters of the Wave 110 RSX motorcycle of Honda manufacturer, which was selected as a test subject in this study due to this vehicle has been the most popular in the Vietnam's market. Fig. 2 presented the experimental setup schematic on dynamometer Chassisdyno 20" for Wave 110 RSX test.

Used fuels for these comparative experiments were E5 (5% of bioethanol and 95% of RON95), E10 (10% of bioethanol and 95% of RON95), and E0 (100% of RON95) that satisfied the latest National Technical Regulation requirements. The engine power (N_e), thermal efficiency (η_e), fuel consumption (g_e), and emission characteristics as a function of speed curve were measured, determined at the 3rd and 4th gear with accelerator pedal at 100% in case of from 20km/h to 80 km/h with step 10 km/h of speed range. Vietnamese standard 7357:2010 assisted the monitor, and as-selected test cycle ECE R40.

Table II
Primary parameters of test Wave 110 RSX motorcycle

Brief description	Parameters
Type of motorcycle	Honda Wave 110 RSX
Type of engine	Air - cooled - 4 stroke and 1 cylinder gasoline engine
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

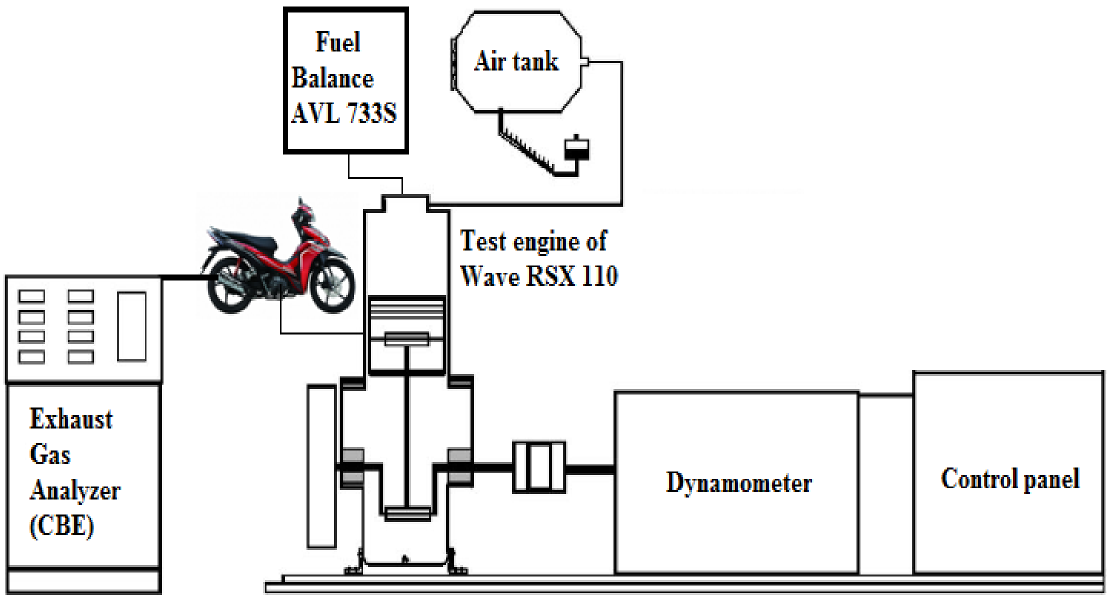

Fig.2. Schematic of Wave RSX 110 motorcycle test on the dynamometer Chassisdyno 20"

III. Results and Discussion

A. Engine performance

The engine power of test motorcycle at the 3rd and 4th gear is shown in Fi. 3 and Fig. 4. The test motorcycle power as using E10 is enhanced at all speed as running at the 3rd and 4th gear compared to RON95 and E5. At the 3rd gear, the maximum difference about engine power as using E10 is 9.95% at 70 km/h of speed compared to RON95 and 6.78% at 40 km/h compared to E5. However, at the 4th gear, the maximum difference about engine power as using E10 is 10.90% compared to RON95 and 4.59% at 40 km/h of speed compared to E5.

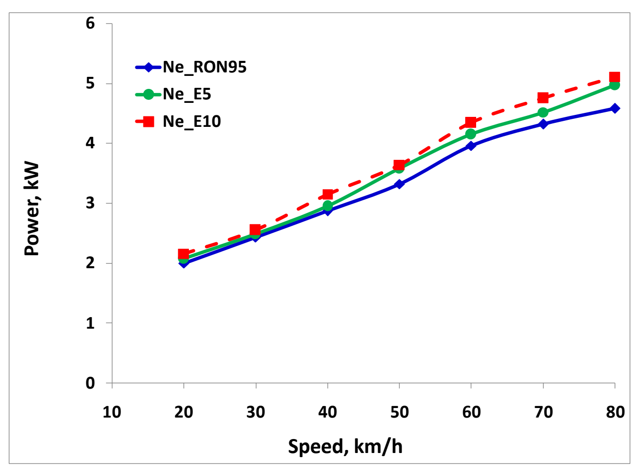

Fig. 3. Engine power at the 3rd gear

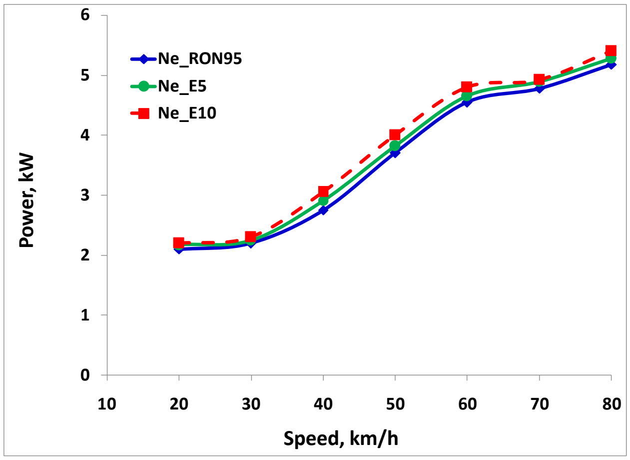

Fig. 4. Engine power at the 4rd gear

On the speed range, the engine power operated by E10 is 6.52% and 4.01% higher than that of RON95 and E5, respectively as engine ran at the 3rd gear. This value tends to be lower as running at the 4th gear, fact that, it only increase 7.41% and 5.85% compared to RON95 and E5. This increase in engine power may be explained with many reasons. Although the heating value of E10 or E5 is lower than that of RON95 but the presence of oxygen in E5 and E10 is considered as beneficial effect for more complete and cleaner combustion. Moreover, 4.3% of ethanol density higher than RON95 results in a larger fuel injected into the combustion chamber for the same volume. In addition, higher evaporation latent heat of ethanol–gasoline blended fuel (E5 and E10) compared to gasoline provided lower temperature in intake manifold and increase of volumetric efficiency. Besides, the PGM-FI fuel system for Wave RSX 110 is set to use pure fossil gasoline, the ratio of air– fuel stoichiometry for pure fossil gasoline is approximately 14.7:1, and this value should be lower than 14.7 for blended fuel.

Gasoline: $C_7H_{13.3} + 51.56(0.2\ O_2 + 0.79\ N_2) = 7CO_2 + 6.66H_2O + 40.73\ N_2 + 47.3$ MJ/kg

Ethanol: $C_2H_6O + 15(0.2\ O_2 + 0.79\ N_2) = 2CO_2 + 3H_2O + 11.85\ N_2 + 29.7$ MJ/kg

The intake air is remained at constant amount, as the engine speed increases, the engine tends to be operated in rich fuel conditions. Hence, the equivalence ratio of air per fuel increases to higher value as added ethanol that results in the burning process closer to the stoichiometry, and achieved higher power output may be considered as an upshot from better combustion.

Figs. 5 and 6 show the measured fuel consumption (g_e) following to the external feature of Wave 110 RSX motorcycle as operated at the 3rd and 4th gear. At all speed range, (g_e) for E10 is lower than that of E5 and RON95, even though different decreased-levels. While motorcycle runs at the 3rd gear and under 35 km/h of speed, the mean reduction (g_e) of E10, E5 is around 3.35%, 1.74% respectively, compared to gasoline RON95. However, at higher speed, the mean reduction (g_e) of E10, E5 compared to gasoline RON95 is around 5.17%, 2.94% respectively. On whole of speed range, the (g_e) of E10, E5 is 4.26%, 2.34% lower than that of RON95. The maximum (g_e) of E10 is 424.21 (g/kW.h), of E5 is 428.15 (g/kW.h) compared to 432.18 (g/kW.h) of RON95 at 20 km/h of speed, the minimum (g_e) of E10 is 378.14 (g/kW.h), of E5 is 389.08 (g/kW.h) and of RON95 is 399.16 (g/kW.h) at 50 km/h of speed.

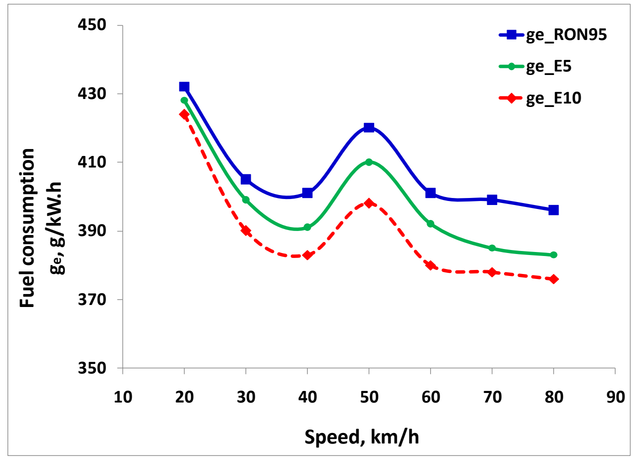

Fig. 5. Fuel consumption at the 3rd gear

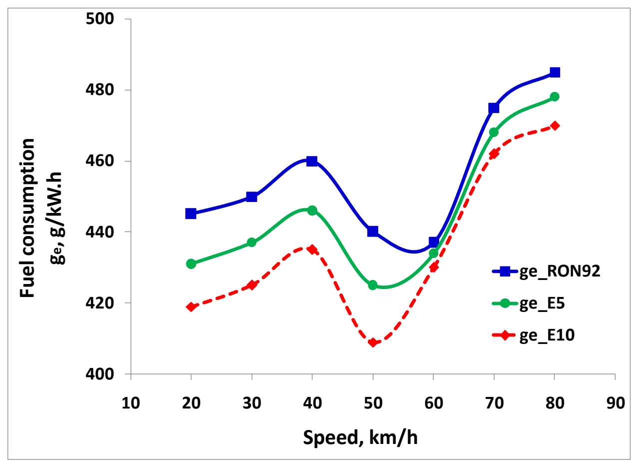

Fig. 6. Fuel consumption at the 4rd gear

The reduction of (g_e) is a contrary trend as the engine runs at the 4th gear, at below 50 km/h of speed, the (g_e) of motorcycle engine fueled with E10, E5 is around 6.01%, 2.99% lower than that of RON95. Nevertheless, at higher speed, the reduction in (g_e) of E10 and E5 is only about 2.47%, 1.29%.Thus, the (g_e) of E10, E5 is 4.24%, 2.14% lower than that of RON95 with whole of speed range. The maximum (g_e) of E10 is 470.11 (g/kW.h), of E5 is 477.92 (g/kW.h) compared to 485.20 (g/kW.h) of RON95 at 80 km/h of speed, the minimum (g_e) of E10 is 409.22 (g/kW.h), of E5 is 424.96 (g/kW.h) and of RON95 is 437.18 (g/kW.h) at 50 km/h of speed. The change trends of (g_e) as using E10, E5 and gasoline are also proper with the above results presented about engine power. Due to the structure of carburetor - fuel system of Wave RSX 110 motorcycle is kept constantly, hence provided mass of fuels at the measured modes of engine are homologous. This led to corresponding changes of (g_e) while the engine power changes. Similar results are denoted in some last studies from Paolo I et al. (2014) and Maria A.C et al. (2016).

In the internal combustion engine, the thermal efficiency (η) has a connection with the fuel energy (Q)-converted-obtained power (N_e) in the combustion. The (η) may be determined versus LHV and (g_e) followings as Eq.(1).

$$\eta = \frac{3600}{(g_e)(LHV)} \quad (1)$$

Thermal efficiency (η) of motorcycle engine is plotted in Figs. 7 and 8, (η) is plotted at 100% of load and the changed speed. A 2.15% of increase in thermal efficiency of E10 in comparison with RON95, 1.12% compared to E5 at the 3rd gear; and at the 4rd gear with 1.02% of increase in thermal efficiency of E10 compared to RON95, 0.25% compared to E5 is achieved by improving the advance of spark, and also reducing the work in compression process. The essence of the processes of the compression and the combustion is necessary to discus and explain the essence if increase in (η). The continuance of fuel vaporization during the compression stroke results in the trend of reduction in the temperature of the charge, and of course reduction in the compression work. Otherwise, the increase in the vapor quantity in the charge led to the increase of the compression work. In case of ethanol-blended-gasoline with the higher latent heat than pure fossil gasoline, the influence of additional vapor certainly overcomes the cooling effect. Along with higher latent heat, the higher temperature of auto-ignition of ethanol is a main cause results in advanced spark timing compared gasoline. These lead to the ability of increasing the compression ratio, and of course, engine thermal efficiency (η) and power is ameliorated because of a part dependence of engine thermal efficiency (η) on combustion efficiency. The lean equivalence ratio or reduction of engine operation with rich fuel as insufficient oxygen to combust perfectly, thoroughly, and completely in high combustion efficiency. Therefore, more provided oxygen from ethanol for the combustion gives a supplementary support to burn the lean mixture. The improved engine thermal efficiency (η) is the final result.

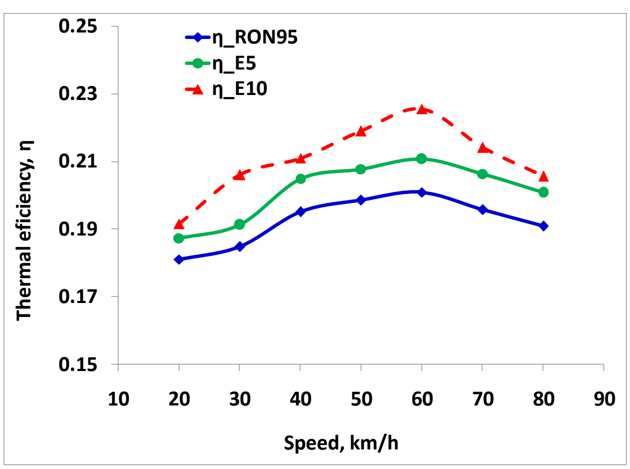

Fig.7. Thermal efficiency (η) at the 3rd gear

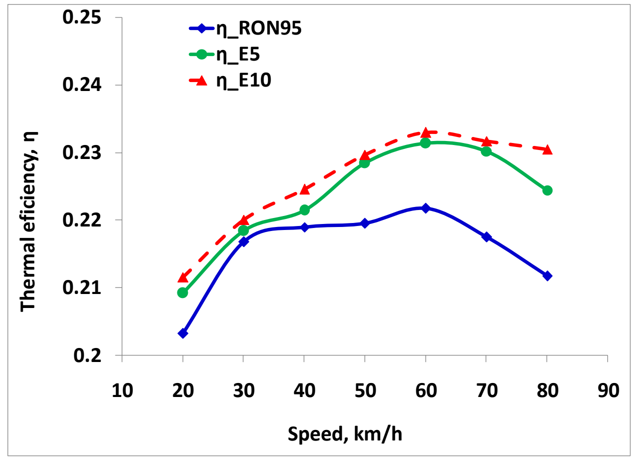

Fig. 8. Thermal efficiency (η) at the 4rd gear

B. *Emission characteristics*

In the combustion process, hydrocarbon peroxide radicals (-ROOH) are formed by broking down the alkane molecules by dehydrogenization process and shown in Fig. 9. The creation of the H•, O•, and OH• radical is the subsequent reactions in the fuel disintegration (Richard van B et al, 2017). Some hydrocarbons such as light alkenes (C_2H_4, C_3H_6), and alkine (C_2H_2), and ultimately aldehydes such as aldehyde axetic (CH_3CHO), aldehyde formic (HCHO) are the initially created by the chain propagators. Approximately 10% of heat is discharged during aldehydes formation, the hydrocarbons oxidation to CO- released-heat is about 40%, and remained heat value for oxidation conversion of CO into CO_2 is 45%. Above value shows that, more provided oxygen from oxygenated fuel supported the complete combustion and the conversion of CO into CO_2, and more released heat resulted in improving the thermal and combustive efficiency.

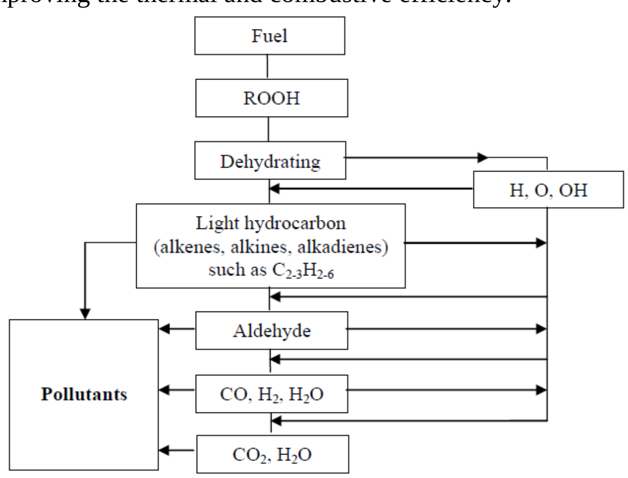

Fig.9. Schematic of emission formation

CO emissions characteristic of test motorcycle using E10 compared to RON95 ad E5 is shown in Fig. 10 with a 9:1 of compression ratio. The more incomplete the combustion is, the more the CO emission concentration increases. The operating condition of each engine and the ratio of air-fuel are considered as the main factors, which affect directly to CO emission concentration. However, the dissociation is mentioned as a reason of increasing CO concentration even through at lean mixture which reduced proportional to combustion temperature. Average result about CO emission as using E10 at the 3rd gear showed the reduction of 1.85% and 5.24% in comparison with E5 and RON95, respectively. This reduction value at the 4th gear is 1.65% and 4.66% in comparison with E5 and RON95, respectively. Moreover, the CO emissions of motorcycle meeting the ECE R40 test cycle show the results with 4.582 g/km, 4.376 g/km and 4.118 g/km appeared in the test fuel of RON95, E5 and E10 respectively. Thus, the CO emission from E10 is 10.12% lower than that of RON95, 5.89% lower than that of E5. In the contrary direction, CO_2 emissions tend inversely proportional to CO emissions. The CO_2 emissions for RON95, E5, and E10 are 35.291 g/km, 36.678 g/km, and 37.823 g/km, respectively. Results prove the positive effect of oxygen presence on combustion process.

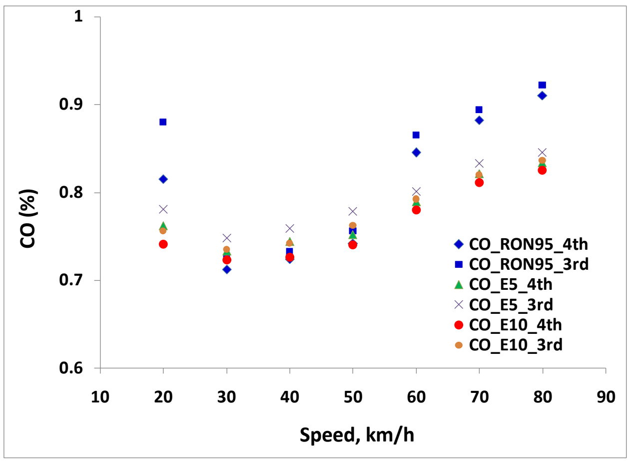

Fig.10. CO emissions characteristic

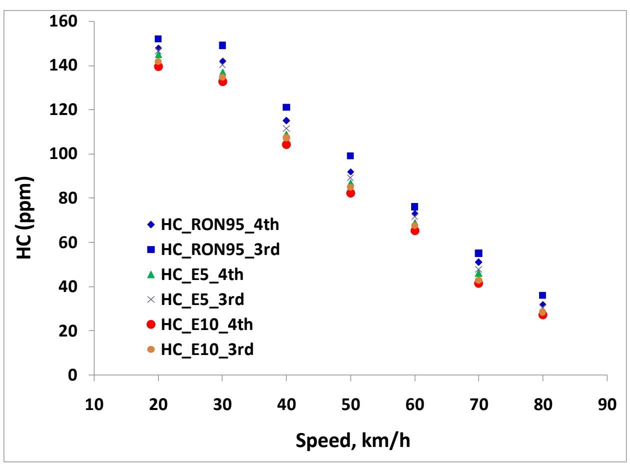

Fig.11. HC emissions characteristic

HC emissions concentration shown in Fig. 11 are involved closely with engine design and operating condition. Normally, some engine design factors such as combustion chamber figure, the number of stroke, the size of bore, the value of compression ratio are primary ones affect to HC emissions. Generally, a dramatic reduction in HC emissions level is a result of sufficient oxygen supplying the combustion process. However, incomplete combustion in the engine because of operating over lean mixture (λ>1.1), frequent misfire resulting in unburned fuel and low combustion temperature, high compression ratio are also the causes of high HC emissions. The HC emissions on speed range as using E10 at the 3rd gear show the reduction of 5.54% and 13.78% in comparison with E5 and RON95, respectively. At the 4th gear, this reduction value is 5.36% and 10.84% in comparison with E5 and RON95, respectively. The HC emissions of motorcycle meeting the ECE R40 test cycle are 0.696 g/km, 0.477 g/km, and 0.376 g/km for RON95, E5, and E10 respectively.

Nitrogen oxides (NOx) - mixture of compounds such as NO, NO_2, N_2O, N_2O_3, N_2O_4, and N_2O_5 form at high temperature over 1500ºC, in a reaction from combustion process. In an SI engine, the NOx concentration is invariable regarding the equilibrium level because of in-cylinder limited residence time.

NOx concentration usually peaks as high combustion temperatures and rich oxygen concentration with 1.1 <λ< 1.2. Normally, after getting peak, the reduction in NOx concentration occurs due to the oxygen concentration decreases. In other case such as leaner conditions, the decreasing of combustion temperatures is the main cause resulting in reducing NOx. Fig. 12 shows NOx emission concentration with around λ=1.1 as engine fueled with RON95, E5, and E10.

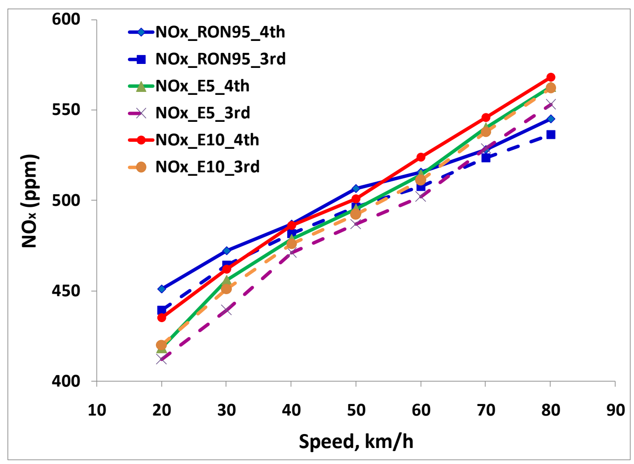

Fig.12. NOx emissions characteristic

At lower speed (<60 km/h), the NOx emissions of engine decreased as operating on E5 and E10 fuel. However, at higher speed (>60 km/h), this trend of NOx emissions occurs contrarily. This result is due to at low speed, the combustion is not good because of lean mixture, and the heating value of RON95 is higher than that of E5 and E10, hence the NOx emission for RON95 is higher than that of E5 and E10. As running at high speed, the air-fuel mixture archives the optimal ratio, besides the appearance of oxygen in biogasoline (3.7% in E5 and 3.93% in E10) assists the combustion to happen more completely and perfectly. About average result on total of speed range, at the 3rd gear, the increase of the NOx emissions of test engine fueled is 1.66% and 2.09% in comparison with E5 and RON95, respectively. At the 4th gear, this increase value is 1.68% and 2.13% in comparison with E5 and RON95, respectively. The NOx emissions according to ECE R40 test cycle were 0.286 g/km, 0.347 g/km, and 0.383 g/km for RON95, E5, and E10, respectively.

Based on these above experimental results, it is proved that, E10 may be considered as potential alternative fuel. Using E10 for current motorcycles in Vietnam is not only improving the economic feature, but also reducing the environmental pollution. These study results help Vietnamese Government to offer the policies and solutions of supporting Bioethanol Production Factories as well as using E10 in the Vietnamese market.

IV. Conclusions

In these study results about determining and measuring the performance and emission characteristics for the most popular motorcycle engine in Vietnam fueled with E10, some conclusions are presented following as: there is around 5%, 0.8%, 2%, 4.5% of increase in engine power, thermal efficiency, NOx emission, CO2 emission, respectively. In addition, a reduction in 3.2%, 3.8%, 9% of fuel consumption, CO emission, HC emission, respectively, as using E10 fuel in comparison with fossil gasoline-RON95 and E5 are indicated in this study. Besides, no adjustment of motorcycle structure as well as fuel system when converts motorcycle into using E10 is considered. However, it is necessary to evaluate the durability, longevity, safety in fire and explosion of engines for this fuel before using in the market.

Acknowledgment

The authors are pleased to acknowledge Mechanical Engineering Faculty Ho Chi Minh city University of Transport, School of Transportation Engineering - Hanoi University of Science and Technology for supporting this research.

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