American Journal of Applied Sciences 9 (5): 647-653, 2012
ISSN 1546-9239

The Use of E100 to Fuel a Used 4-Stroke Motorcycle

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Abstract: Problem statement: Though ethanol and gasohol are proved to be used as alternative fuels in vehicles, 4-stoke motorcycles used nationwide mainly consumed gasoline 91/95. **Approach:** The motorcycle tested, the used Honda Wave125 model, was properly tuned at the rich relative air-fuel ratio (λ) 0.85, which theoretically gave the maximum power output. For the use of E100, the engine required richer air-fuel mixture condition, the main nozzle and idle nozzle sizes were therefore increased from the sizes used for gasoline91; by 21.4% from 0.78 mm for the main nozzle and 76% from 0.35 mm for the idle nozzle. Due to having three times higher in heat of vaporization, the stronger current ignition coil was used instead. This eased the engine starting without any trace amount of gasoline. The ignition timing was advanced by about $+9^{O}$crank angle to suit E100's high octane number of 107. **Results:** The performance test results of E100 on dynamometer showed that the maximum power output was 9 hp@7428 rpm and the maximum torque was 11 Nm@4728 rpm. Comparing to the use of gasoline91, the engine performance decreased 12-15% over the speed range of around 4000-8000 rpm. From the road tests; city road test and long driving test, at the average speed of 60 km h^{-1}, the average consumption rate of E100 was about 25-28% more. The calculated fuel conversion efficiency of E100 was 38.2% higher. For emission measurements when using E100, the concentrations of CO and of HC were 3.14 vol % and 2143 ppm. Those were higher than in the exhaust of the use of gasoline91 but below the regulations which required <4.5vol % for CO concentration and <10,000 ppm for HC concentration. Though the NOx concentration in the exhaust of all tests was not measured, high NOx concentration was observed in the lean mixture at λ >1.0 condition. Since a particular instrument was not available, aldehyde concentration in the E100's emission was not measured. **Conclusion:** It clearly confirmed that E100, 95.5 vol % ethanol, can be effectively used as an alternative fuel in used 4-stroke motorcycles whose carburetors were purposely designed for the use of gasoline91. If the engines were properly tuned up and modified to best suit the E100's characteristics while maintaining the compression ratio, the motorcycles performed as efficient as fueling gasoline91.

Key words: Rich relative, air-fuel ratio, conversion efficiency, while maintaining, compression ratio, lean mixture, long driving, maximum torque, fueling gasoline91, not measured

INTRODUCTION

The imbalance of world oil supply and demand, its price fluctuation and political instability in oil producers caused energy crisis and suffered world economic. In addition, environmental problems, air pollution and global warming, have become urgent issues for all to concern. Emission from burning fossil fuels is a major contribution to air quality, mainly big cities dense in population and vehicles. Consequently, more stringent and tighten emission standard and requirements are needed. Thailand is an agricultural country and a net oil importer. Agricultural products like sugar cane and cassava are suitable feedstock for ethanol production. Cassava and molasses are often surplus and exported in raw. The surplus will provide higher value if they are used as ethanol feedstock. This will certainly create sufficiency and sustainable economy in various sectors; agricultural, transportation, automotives and the related industries (DEDE, 2009).

Ethanol and gasohol, the blend of gasoline and ethanol, are proved to be used as an alternative fuel in automobiles. Ethanol is a clean biofuel with similar characteristics to gasoline, the study of the use E100, 95.5% vol ethanol, in the 4-stroke motorcycles is encouraged. Over 20 million motorcycles consuming gasoline 91/95 have been used nationwide, in particular, for low and middle incomes (CM, 1993). Typically, the 4-stroke motorcycle engines use carburetor to meter the appropriate fuel flow for the engine air flow. The study of the use of E100 as an alternative fuel in a used motorcycle-carburetor type will be conducted as follows: engine performance, fuel consumption and emission.

In spark ignition engines, the fuel is normally mixed with air in the engine intake system. Combustion of the fuel-air mixture reacted inside the engine cylinder controls engine power, efficiency and emissions. The stoichiometric proportion of fuel and air is the theoretical proportion of enough oxygen for conversion of the all the fuel into completely oxidized products. That is, the carbon in the fuel is then converted to carbon dioxide CO_2 and the hydrogen to water H_2O. Fuel-air mixtures with more than or less than the theoretical air requirement can be burned. With excess air or fuel-lean combustion, the extra air in unchanged forms appears in the products. Under the fuel-rich mixtures, the incomplete combustion occurs because there is insufficient oxygen to oxidize fuel carbon and hydrogen. The incomplete combustion products are a mixture of CO_2 and H_2O and carbon monoxide CO and hydrogen H_2 as well as nitrogen N_2. The composition of the combustion products is significantly difference for fuel-lean and fuel-rich mixtures and the stoichiometric air-fuel ratio or fuel-air ratios depends on fuel composition (Pulkrabek, 2004; Taylor, 1966). The fuel-air equivalence ratio, ϕ, and the relative air-fuel ratio, λ, is therefore defined as follows Eq. 1:

$$\varphi = \frac{\left(\frac{A}{F}\right)_{stoic}}{\left(\frac{A}{F}\right)_{actual}} = \frac{1}{\lambda} \quad (1)$$

For fuel-lean mixtures: $\phi<1:\lambda>1$

For stoichiometric: $\phi=\lambda=1$

For fuel-rich mixtures: $\phi<1:\lambda>1$

The spark ignition engine has normally been operated close to stoichiometric or slight fuel-rich to ensure smooth and reliable operation. About 10-15% fuel rich mixture will produce best torque which results in best power and fuel-lean mixture by a similar amount will produce best economy. Since the amount of CO can be used as a measure of fuel rich condition, the amount of O_2 must be used to provide a measure of fuel-lean condition. NOx depends on temperature and pressure (Pulkrabek, 2004); it reaches a peak with slightly fuel lean condition.

The stoichiometric combustion reaction of gasoline is Eq. 2:

$$C_8H_{16} + 12(O_2 + 3.776N_2) \rightarrow 8CO_2 + 8H_2O + 45.312N_2 \quad (2)$$

And $\left(\frac{A}{F}\right)_{stoic} = 14.8$. For ethanol, C_2H_5OH the stoichiometric combustion reaction is Eq. 3:

$$C_2H_5OH + 3(O_2 + 3.776N_2) \rightarrow 2CO_2 + 3H_2O + 11.32N_2 \quad (3)$$

And $\left(\frac{A}{F}\right)_{stoic} = 9.0$. The ratio of the study produced per cycle to the amount of fuel energy supplied per cycle that can be released in the combustion process is commonly used to measure engine's efficiency. The fuel conversion efficiency, η_f is given by Eq. 4 and 5:

$$\eta_f = \frac{W_c}{m_f Q_{HV}} = \frac{P}{\dot{m}_f Q_{HV}} \quad (4)$$

$$\eta_f = \frac{1}{(sfc)Q_{HV}} \quad (5)$$

Where:

W_c = Work per cycle

P = Power

m_f = Mass of fuel which can be replaced by the average mass flow rate, $\dot{m}_f$

The specific fuel consumption sfc, is defined as Eq. 6:

$$sfc = \frac{\dot{m}_f}{P} \quad (6)$$

The fuel conversion efficiency, thermal conversion η_t and combustion efficiency η_c are related as Eq. 7:

$$\eta_f = \eta_c \eta_t \quad (7)$$

Actual combustion processes are complex and often incomplete, even in the presence of considerable excess air. It is more practical to analyze the products experimentally. Exhaust gas composition depends on the relative proportions of fuel and air fed to the engine, fuel composition and completeness of combustion (Wertheimer, 2009). In practice, the exhaust gas of an internal combustion engine contains complete combustion products; CO_2 and H_2O, as well as incomplete combustion products; CO, H_2, unburned hydrocarbons and soot.

The shapes of emission curves indicate the complexities of emission control as shown in Fig. 1 AJ6 Engineering. Use of alcohol fuels in either spark ignition engine or diesel engine substantially increases aldehyde emissions (Pulkrabek, 2004). While these are not yet subject to regulation, aldehyde would be a significant pollutant if these fuels to be used in quantities comparable to gasoline and diesel.

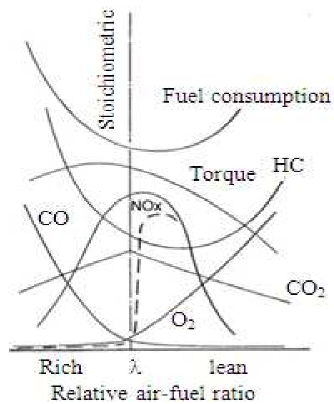

Fig. 1: Relationship between torque fuel

MATERIALS AND METHODS

The motorcycle tested, Honda Wave 125, was used over 10,000 kilometers; the engine conditions must be thoroughly inspected before conducting the tests.

- Fuel system
- Fuel tank-inspect rust and leak
- Fuel line-inspect crack, if any, such line must be replaced
- Carburetor-cleanse deposits/soot
- Air filter-change to a new air filter
- Transmission system-inspect chain stretch and sprockets wear, to assure all being in good condition. Normally, those are required periodic replacement
- Brake system-inspect brake conditions and brake pad thickness. After repeated use, the brake pads surfaces wear away, the pad is periodically replaced
- Lubrication system-thoroughly inspected. If there is any leak or seep, it must be fixed. Then, the brand new lubrication oil will be used

The motorcycle tested was long used; the dynamic compression must also be tested.

Equipments list:

- The used 4-stroke motorcycle, Honda Wave 125
- Test fuels: Gasoline91 and E100 (95.5% vol)
- Dynamometer (Martyr and Plint, 2007)
- MoTec Professional Lambda (λ or Relative Air-Fuel Ratio) Meter
- Emission Gas Analyzer-OPUS20
- Protune compression tester kit

Performance test on dynamometer:

- Tight the motorcycle tested firmly on the dynamometer and then calibrates the engine speed (rpm)
- Start the engine, then full accelerated at the set gear, the 2nd gear selected for this test
- Cut off the transmission system. Torque and power output were computed and graphically displayed
- Apply brake and turn off the engine

Fuel consumption: Mileage and fuel consumption were collected from the following test conditions:

- City road test at the average speed of 60 km h^{-1} The test data were collected from daily riding in the city at the average speed of 60 km h^{-1}
- Long riding test at the control speed of 60 km h^{-1}

The long riding was tested on the certain road during 09:00-12:00 h. because of light traffic and nice weather with sunny and breeze. Each trip was about 20 km and the speed was controlled at 60 km hr^{-1}.

Emission measurement:

- While running the engine, insert the oxygen sensor right in the middle of its exhaust pipe (as shown in Fig. 3)
- Record data shown on the screen and then remove the sensor and turn off the engine

Engine modifications:

- To obtain the performance data base of the motorcycle tested using gasoline91, the motorcycle was properly tuned on the dynamometer shown in Fig. 2 at the fuel rich equivalence ratio λ of 0.85 which theoretically gave the best power output
- When changing to E100, the engine was again tuned up on the dynamometer at the same λ of 0.85. The combustion of E100 requires fuel richer condition 9:1 comparing to gasoline of 14.8:1. Beside that E100 has higher octane number, lower heating value and less volatile. Under the concept of cost effective and easy-to-do, the carburetor and the ignition system were modified while maintaining the compression ratio

Carburetor modification: Due to requiring fuel richer mixture condition of E100, when tuning up on the dynamometer at the λ of 0.85, the main nozzle size and the idle nozzle size were increased by 30.7 and 85.7% from the sizes used for the use of gasoline 91; 0.78 mm for the main nozzle size and 0.35 mm for the idle nozzle size. However, the riding performance was not as smooth as fueling with gasoline 91. It was also experienced high concentrations of CO and HC in exhaust measurements (TC, 2006). To attain smooth running and low incomplete combustion compounds in exhaust, the engine was again fined tuning on the dynamometer at the same λ 0.85.

Fig. 2: Performance test on a dynamometer

Fig. 3: Emission measurement

Table 1: Fuel characteristics (Heywood, 1988; Cengel and Boles, 2010)

Properties	Ethanol	Gasoline
Chemical formula	C_2H_5OH	$C_{8.26}H_{15.5}$
Molecular weight	46.070	114.8
Specific gravity	0.785	0.72-0.78
Oxygen content (wt %)	34.800	-
Reid Vapor Pressure @38°C (kPa)	16.000	48-108
Boiling point (^{O}C)	78.000	27-225
RON	107.0000	80-90
Heat of Vaporization (MJ/kg)	0.919	0.350
Lower Heating Value (MJ/kg)	26.800	44.0
Flash point (°C)	13.000	-43-39
Auto-ignition Temperature (°C)	360.000	260-460
Flame temperature (°C)	1920.000	2030
Adiabatic Flame Temperature (K)	2117.000	92-98
MON	89.00	2315

It resulted in increasing the main nozzle by 21.6% and idle nozzle sizes by 76.4% of the sizes used for fueling gasoline91. The engine gave better performance, smooth riding and lower CO and HC concentrations in the exhaust.

Ignition system: For using high octane fuel, the ignition timing can be advanced within 5-10^{O} crank angle. Since E100 (95.5% vol ethanol) has high octane number of 107 as shown in Table 1, the ignition timing was advanced, about +9^{O} crank angle for this test. In addition, heat of vaporization of E100 was 0.919 MJ kg, about three times higher than gasoline91 of 0.350 MJ kg^{-1} (see Table 1). The 20000V ignition coil supplying stronger ampere was therefore being used. As a result, the engine was easily started without any trace amount of gasoline.

RESULTS AND DISCUSSION

Performance test results on dynamometer: After fine-tuning the motorcycle tested for using E100 on the dynamometer at the relative fuel rich ratio λ of 0.85, its power and torque were graphically compared to those using gasoline 91 in Fig. 4. When using E100, the maximum power output was 10% lower at slightly higher speed but giving the same maximum torque at higher engine speed.

It confirmed that E100 can be used as alternative fuel if the engine was properly tuned up and modified while maintaining the compression ratio.

Fuel consumption test results: The comparative results between the consumption rate of gasoline91 and E100 collected from both conditions displayed in Fig. 5. It showed that the consumption rate of E100 (3) and (6) were about 25-28% more than those of gasoline 91. Note that the engine was operated in fuel richer condition for E100 and E100 has heating value of 26.8 MJ kg which was about 39% lower than gasoline, 44 MJ kg. However, the test results showed that E100 gave better fuel conversion efficiency 38.2% higher than gasoline as shown in Table 2. Therefore, E100, 95.5% vol ethanol, can be effectively used as an alternative fuel for 4-stroke engines without the aid of gasoline if the engines were properly modified and tuned up while maintaining the compression ratio.

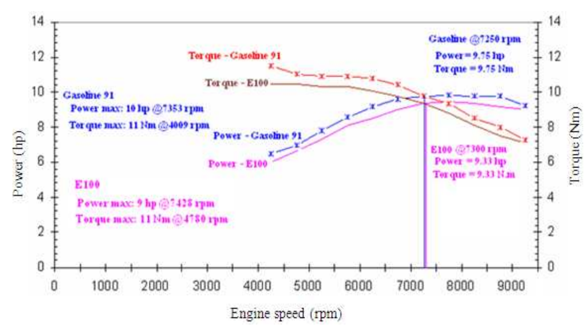

Fig. 4: Comparison of performance test results on the dynamometer between the use of E100 and Gasoline91 -after the adjustment of carburetor and ignition system

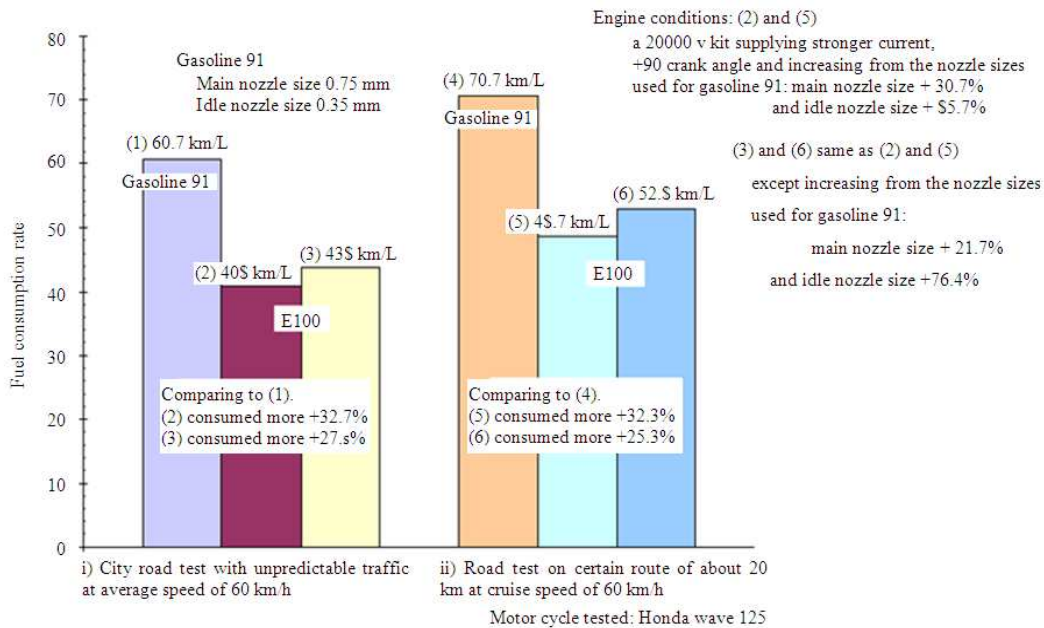

Fig. 5: Comparison of consumption rate of E100 and gasoline 91 used in the 4-stroke motorcycle after the modification of carburetor and ignition system

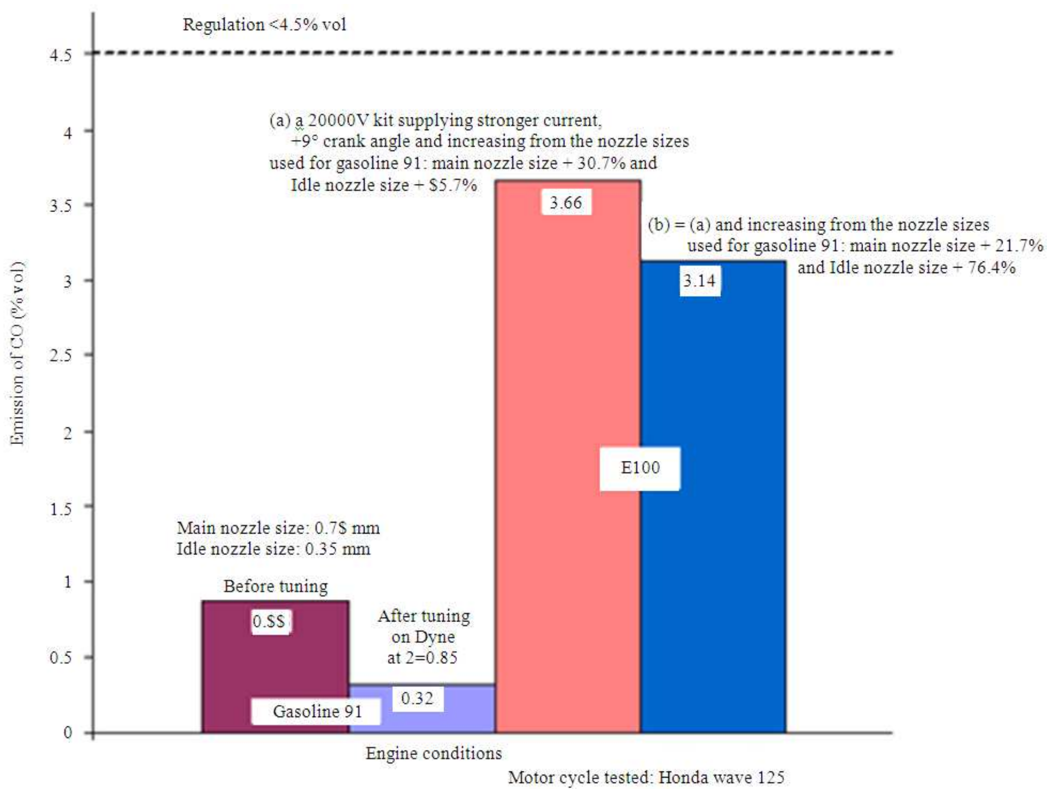

Fig. 6: Comparison of CO concentration in the exhaust of the 4-stoke engine the use of gasoline91 and E100 after the modification of carburetor and ignition system

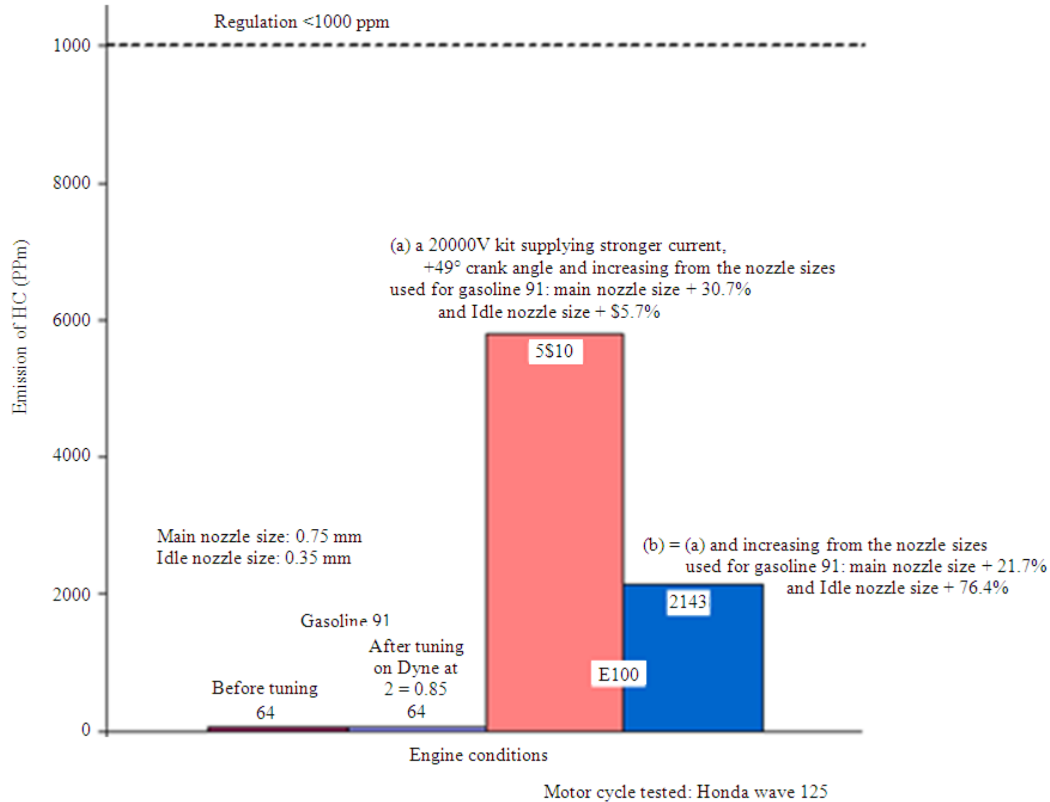

Fig. 7: Comparison of HC concentration in the exhaust of the 4-stoke engine the use of gasoline91 and E100 after the modification of carburetor and ignition system

Table 2 Comparison of fuel conversion efficiency

Details	Gasoline91	E100
Density[2] @ 15°C, kg m^{-3}	0.7381	0.789
mass flow rate (m_f), kg/s	0.7381×10^{-3}	0.7381×10^{-3}
Low heating value (MJ/kg)	44	26.8
Theoretical air-fuel ratio	14.8:1	9:01
Maximum power output[3] (P_{max}), hp	10	9
Fuel conversion efficiency (η_f)	$\eta_{f,RON91}$	$1.382\eta_{f,RON91}$

Notes: 1. fuel volume 1 L and 1 hp = 0.746 kW 2. Manufacturers' laboratory results-Bangchak Petroleum Public Co. Ltd. and Ekarat Pattana Co. Ltd

Emission measurement: The motorcycle tested has been long used and its carburetor was purposely designed for the use of gasoline91. Before testing, it was thoroughly inspected as well as tested its dynamic compression. The engine was properly tuned up on dynamometer and then modified for the use of E100 while maintaining the compression ratio. Higher CO and HC concentrations in the exhaust were observed as shown in Fig. 6 and 7. Those were below the regulations which required <4.5% vol for CO concentration and 10,000 ppm for HC concentration. Though NOx concentration of all tests was not measured, high NOx concentration was observed in the lean mixture condition, particularly peak at λ 1.05. For aldehyde emission while using alcohol fuel, it was not measured since a particular analyzer was not available. However, aldehyde was not yet added in the pollutant regulation from the exhaust.

CONCLUSION

It clearly confirmed that the E100, 95.5% vol ethanol, can be effectively used as an alternative fuel for the used 4-stroke motorcycle whose carburetor was purposely designed for the use of gasoline91; the engine was properly tuned up and modified while maintaining the compression ratio. The motorcycle tested was the used 4-stroke Honda Wave 125 which was used over 10,000 km. To achieve as smooth and reliable operation as fueling gasoline91, the motorcycle tested was properly tuned at the rich relative air-fuel ratio λ of 0.85 which theoretically gave the best power output. The operating condition of E100 required fuel richer mixture, the main nozzle size and the idle nozzle size were increased from the sizes used for gasoline91; 21.7% from 0.78 mm for the main nozzle size and 61.7% from 0.35 mm for the idle nozzle size. The stronger current ignition coil of 20000V was used to ease engine starting. Though E100 has three times higher in heat of vaporization, the engine can be started without any trace of gasoline91. Due to E100 having high octane number of 107, the ignition timing was then advanced about $+9^{O}$ crank angle.

Comparing to the use of gasoline91, the dynamometer test result of using E100 showed that the maximum power output was only 10% lower. From the road tests of both city riding and long riding at the average speed of 60 km h^{-1}, the average consumption rate was 25-28% more. E100 gave better fuel conversion efficiency, 38.2% higher. The average concentrations of CO and HC in the exhaust were 3.14% vol and 2143 ppm. Those were higher than in the exhaust of using gasoline91, 0.32% vol CO concentration and 64 ppm HC concentration, but below the regulations. In conclusion, the engine is properly modified and tuned up to suit the fuel's characteristics, such fuel can be alternatively used.

Recommendations:

- For all operating condition, Electronic Control (ECU) of fuel injection would be more appropriate
- From the use of E100, it experienced that lubricating oil became less viscous at shorter distance. Note that lubricating oil is petroleum-base product like gasoline. When fueling E100, 95.5% Ethanol and 4.5% water, the reaction of lubricating oil and alcohol fuel resulted differently. For the use of E100, the changing schedule of lubricating oil would be more frequent
- Since ethanol is a corrosive substance, frequent inspection of fuel system, in particular rubber and plastic materials, is needed. More tests are needed for confirmation

ACKNOWLEDGEMENT

The study was conducted successfully with the great supports from Ekarat Pattana Co. Ltd., Bangchak Peteroleum Public Co. Ltd., A.A.S Autoservice Co. Ltd. and College of Engineering, Rangsit University. Ekarat Pattana Company provided the quality sample of 95.5% Ethanol and gasoline 91 from Bangchak Peteroleum Company (BCP). The A.A.S Autoservice Company gave valuable technical advice along with standard testing equipment, dynamometer.

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