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바이오 가스 이륜차 기관의 성능 특성 연구

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An Investigation of Performance Characteristics of A Biogas-Fueled Motorcycle Engine

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Abstract >> To determine the performance characteristics of motorcycle engine using biogas for practical use, the intake system of a 110 cc motorcycle engine is properly modified to operate with biogas as a fuel. Biogas is a potentially renewable fuel for replacing gasoline in future, but it has high percentage of CO_2 that could lead to slow the burning rate of biogas-air mixture and cause instability in combustion. Thus, the performance characteristics of biogas-fueled motorcycle engines could be different from those of gasoline motorcycle engines. In this paper, the important parameters of performance characteristics (such as: power output, thermal efficiency, fuel consumption, exhaust emission,…) of biogas-fueled motorcycle engine are studied and estimated with change of engine speed and load. The obtained results when operating with biogas are used to compare with that of gasoline fuel under the same operating conditions. Engine speed in the experimental is changed from 1500 rpm (idle-mode) up to 3500 rpm by a step of 500 rpm. Engine load is changed from zero to maximum load with the help of an exciting voltage device from generator-type dynamometer.

The experimental results show that the tested engine operated with richer biogas-air mixture than that of gasoline-air mixture under the same test conditions. Biogas-fueled engine gives a higher fuel consumption and lower thermal efficiency under the same power output. Brake thermal efficiency of biogas engine is found to be about 3% lower than gasoline-fueled motorcycle engine for whole range of speed. Exhaust emission of biogas-fueled motorcycle engine (such as: CO, HC) is found to be lower than the limitation level of the emission standards of Vietnam for motorcycle engines (CO <4.5% HC <1200 ppm).

Key words : Biogas(바이오가스), Motorcycle engine(이륜차 기관), Power output(출력), Fuel consumption(연료소비), Exhausts emission(배기가스)

1. Introduction

The resource limitation of fossil fuels and the problems of air pollution arising from their combustion have led to widespread researches on the accessibility by new and renewable energy resources. Biogas could be produced from the waste (manure and water) of pig farms with the help of the anaerobic digesters. It is a gas mixture comprising methane gas (CH_4)

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(50-70%) and carbon dioxide (CO_2) (20-40%) that is formed when organic materials, such as livestock's' dung or vegetable matter are broken down by micro-biological activity in the absence of air, at slightly elevated temperatures. Mostly effective temperature is between 40 and 60℃.

In Vietnam, many previous researchers have applied biogas as a fuel for power generation system in agricultural area. Conventional gasoline / diesel engine is also modified to run with biogas[1,2]. In recent years, biogas has been gradually considered to apply to supply for the small capacity generators[3,4]. The last type of internal combustion engine generators using biogas to be renovated or switching from diesel[5] or gasoline engine[6]. These products have been partially commercialized in Vietnam by a number of individual researchers. By this method, biogas can replace fully/partially for gasoline/diesel fuel due to the increase of the fuel price and the electricity price.

These above researches, however, have not yet shown the characteristics of biogas power generation systems and/or the performance characteristics of biogas-fueled engines, the stability of output voltage from the commercial biogas power generation systems due to: (1) the research teams designed and manufactured the biogas generators based on the reference information and/or oversea experiences (mostly from Europe, Australia, India, China,…) where the composition of biogas is very difference from those in Vietnam, (2) The tests and estimation of engine performance characteristics (like brake power, thermal efficiency, specific fuel consumption, exhaust emissions,…) of biogas power generation system/internal combustion engines are limited by the lack of specially testing devices and measuring equipments.

To expand the capacity of biogas application, biogas should be used as fuel for internal combustion engines both on-road engines and stationary engines. It is expected that the performance characteristics of biogas-fueled engine must be studied for a wide change of engine speed and load. Then the obtaining results should be used to compare with operation the conventional fuels (like gasoline or diesel).

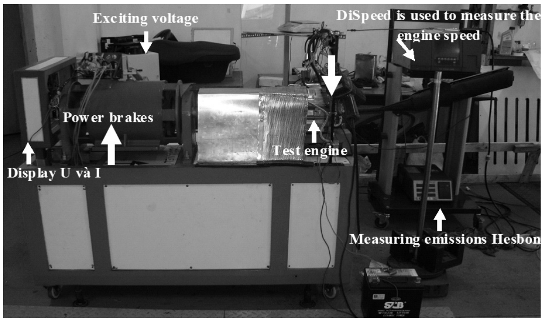

Fig. 1 Experimental setup for motorcycle engine fueled with gasoline in Key-lab for Internal Combustion Engine

Thus, the main objectives of this paper are to evaluate the performance characteristics of biogas-fueled motorcycle engines and to compare with those of gasoline motorcycle engines with change of engine speed and load. In the same operating conditions, the specific fuel consumption, thermal efficiency, and exhaust emission (like CO, HC, NO_x,) are evaluated and compared.

2. Experimental setup and method

2.1 Experimental setup

To determine the performance characteristics of a 110CC motorcycle engine, two separated tests are carried out in the laboratory and at project site where biogas is supplied from the anaerobic digesters, respectively. For the first case, all tests are performed for motorcycle engine fueled with gasoline (Fig. 1) and for the second case (Fig. 2 and Fig. 3), all tests are done with biogas in the same engine.

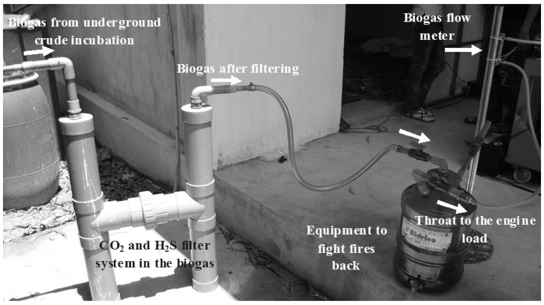

Fig. 2 Experimental setup of biogas supply system for motorbike engine in Tan Uyen, Binh Duong Province

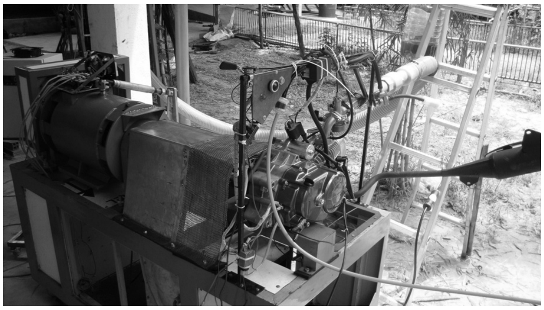

Fig. 3 Experimental setup of biogas-fueled engine at the project site

2.2 Experimental conditions and method

To evaluate comparatively of performance characteristics of motorcycle engine using gasoline and biogas, engine speed is changed from 1500 rpm to 3500 rpm with a step of 500 rpm. A total of five measurement points (1500, 2000, 2500, 3000, 3500 rpm). The parameters recorded at each measurement point included:

1) The voltage and current for each phase;
2) Intake mass flow with ABB Sensy flow (kg/h)
3) Gasoline mass flow (m^3/h);
4) Biogas mass flow (m^3/h);
5) Component of emission by Exhaust Gas Analyzer HESBON (CO_2, HC, NO_x).

2.2.1 Dynamometer

Dynamometer is a generator-type one that includes resistance-type electrical load system and device for exciting voltage (DEV). Voltage (V) and current (I) produced is measured by load system, where U & I is used to estimate the brake power. DEV help to change to the exciting voltage for dynamometer.

2.2.2 Laminar air flow meter

Air mass flow is measured by a sensy flow meter. A valve type is manually used to control air/fuel rates supplied to the intake manifold of test engine.

2.2.3 Biogas mass flow meter

The biogas flow rate supplied to the engine is measured by a biogas mass flow meter. A ball-type valve is installed for manually control.

2.3 Performance parameters

2.3.1 Brake power

The brake power is measured by using:

$$P = \frac{VxI}{1000}$$

Where P is the brake power is developed by the engine, kW; V (Volt) is the voltage produced, V; and I (A) is the current produced.

2.3.2 Brake specific fuel consumption

The mass of fuel consumed was determined by multiplication of the volumetric fuel consumption to its density. In the present set up volumetric fuel consumption for biogas and methane enriched biogas was measure by using a fuel flow meter and then calculated for mass of gas consumption using density of biogas. For gasoline case, the fuel consumption is

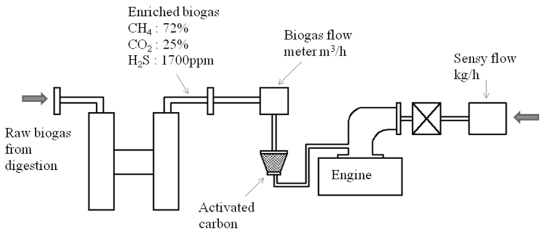

Fig. 4 Schematic layout of experimental engine test setup

estimated by the gasoline consumption in the time interval. The brake specific fuel consumption is calculated by a below equation:

$$BSFC = \frac{M}{P}$$

Where BSFC (g/kW.h) is the brake specific fuel consumption; *M* (g/h) is the mass of fuel consumed; and *P* (kW) is the brake power.

2.3.3 Brake thermal efficiency

The brake thermal efficiency of the engine on gasoline and biogas at different operating loads was determined by using:

$$\eta_{th} = \frac{(Px3600)}{MxLHV}x100$$

Where η_{th} (%) is the brake thermal efficiency; M (g/h) is the consumed mass of fuel; and LHV (MJ/kg) is the lower heating value of fuel.

2.3.4 Relative air/fuel ratio

The estimation of the relative air/fuel ratio was calculated using data of actual air mass flow rate and fuel consumption rates of the engine at operating points and is determined by:

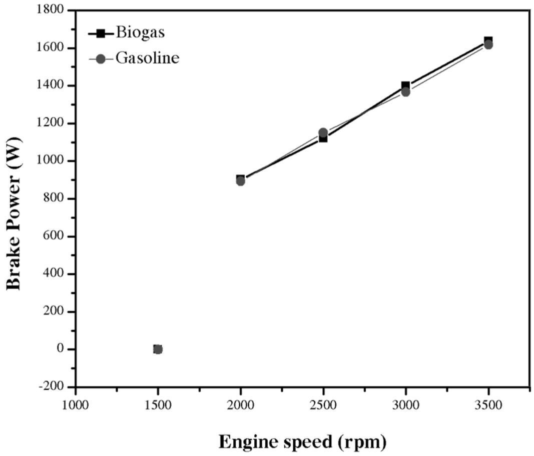

Fig. 5 Variation of brake power versus engine speed

$$\lambda = \frac{Actual - air / Fuel - ratio}{Stoichiometric - ai / Fuel - ratio}$$

3. Results and discussion

3.1 Effects of engine speed

3.1.1 Brake power

In this study, the test engine is installed on the motorcycle engine experimental system. Brake power of engine is measured by an AC dynamometer. The experiments are conducted at the same conditions with biogas and gasoline. Fig. 5 shows, when engine speed increases from 1500 to 3500 rpm, the brake torques for both cases increase. However, the difference in brake power at each operating point is lower than 5%. Engine speed is set at 1500 rpm (idle speed), 2000, 2500, 3000, 3500 rpm.

Theoretically, brake power of same engine fueled with gasoline is higher than that using biogas, because gasoline has higher LHV (Lower Heating Value) (43 MJ/kg) than biogas (27 MJ/kg). In this research, however, brake power (determined by

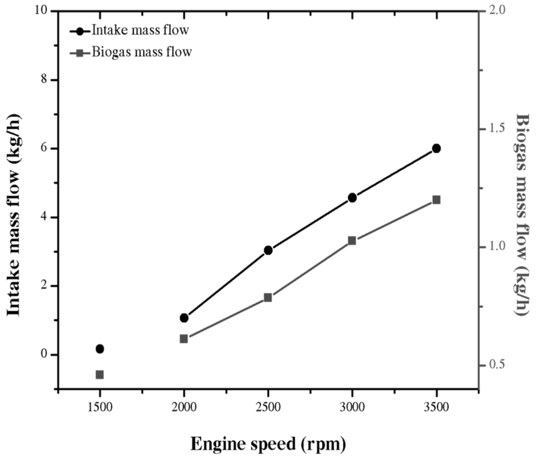

Fig. 6 Variation of intake air mass flow and biogas mass flow with respect to engine speed

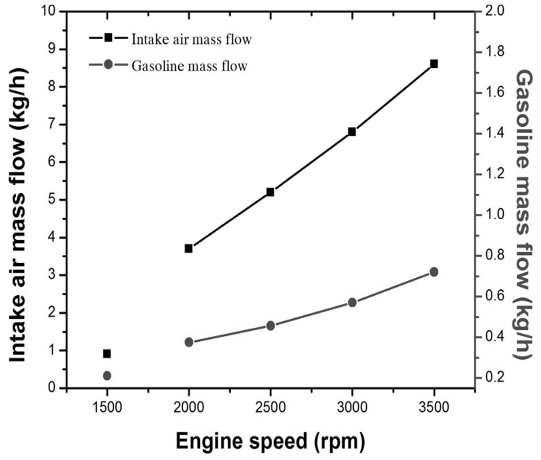

Fig. 7 Variation of intake air mass flow and gasoline mass flow with respect to engine speed

dynamometer) is constantly kept in order to estimate the power out, fuel consumption, thermal efficiency, and exhaust emission...for two study cases.

3.1.2 Intake air and biogas mass flow rate

Fig. 6 shows the change of air mass flow with engine speed. Both intake air flow and biogas flow increase and the variation of A/F rate of air-biogas mixture has a similar tendency. Thus, engine is conducted at the same blend mixture or the same λ at each operating point. At 1500 rpm, air-fuel mixture is quite dense because biogas has high impurities (CO_2 more than 20%), engine is difficult to start and keep stability in low load. In that case, engine need to close air throttle to reduce air mass flow. When engine speed increases up to 2000 rpm, engine operation has conducted smoothly and air mass flow increase relatively linear. That is the main reason leading to increasing of brake power when engine speed increases (Fig. 5).

Varying trends and causes of intake air and gasoline supply in Fig. 7 are quite similar to those shown in Fig. 6. Comparison between Fig. 6 and Fig. 7, it shows that the supplied amount of biogas is higher than gasoline at the same experimental conditions (with the same brake power at each engine speed). This demonstrates that the motorcycle engine operated with biogas needs higher fuel consumption than gasoline operation. To produce the same brake power, in other words, the engine using biogas-air mixture is burned denser than gasoline-air mixture. The main reason, as explained above, is due to lower calorific value of b iogas in comparison with gasoline. This is indicated for brake specific fuel consumption in Fig. 8.

3.1.3 Brake specific fuel consumption (BSFC)

As shown in Fig. 8, for each engine speed, the BSFC of engine operated with gasoline is lower than that operated with biogas. At idle speed of 1500 rpm, BSFC for two cases is almost similar without load conditions. Measurement and estimation at idle speed is used as an important reference for estimation of CO and HC emission that is below discussed. When speed engine increase from 2000 to 3500 rpm, the difference of BSFC is about 40%. This is caused by the increase of consumpted fuel for the operation of

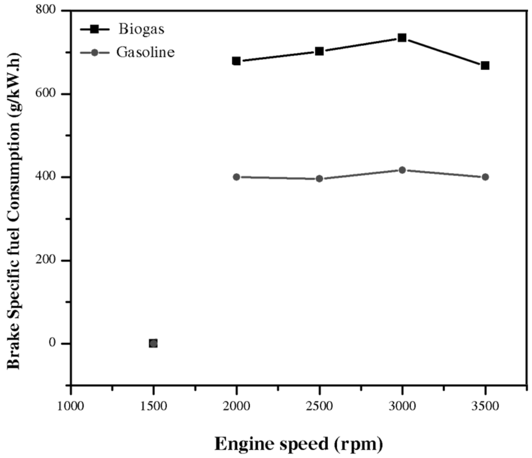

Fig. 8 Comparison BSFC of two cases with respect to engine speed

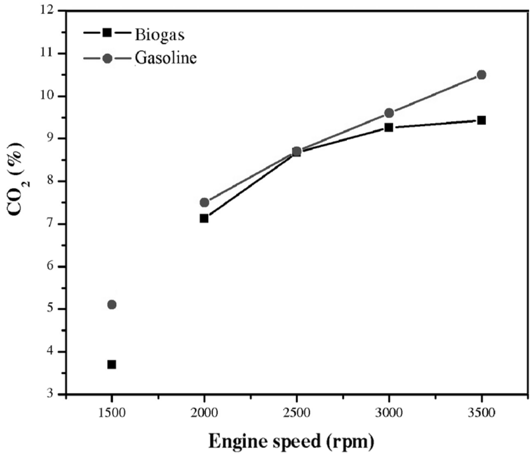

Fig. 10 Variation of concentration of CO_2 versus engine speed for two cases

same power.

3.1.4 Thermal efficiency

Thermal efficiency of engine is inversely proportion to BSFC tendency and LHV of tested fuel. In Fig. 8, the BSFC of engine using biogas is higher than that of using gasoline. Thus, for whole range of engine speed, thermal efficiency of biogas-fueled motorcycle engine is lower as shown in Fig. 9. The reason is biogas has many impurities (CO_2 = 24.4%, O_2 = 1%, H_2S = 0.17%, other component = 4.43%) limiting the combustion and mechanical durability of the engine. Reduction in brake power of engine lead to reduce thermal efficiency. In addition, thermal efficiency of biogas operation is lower by lower heating value.

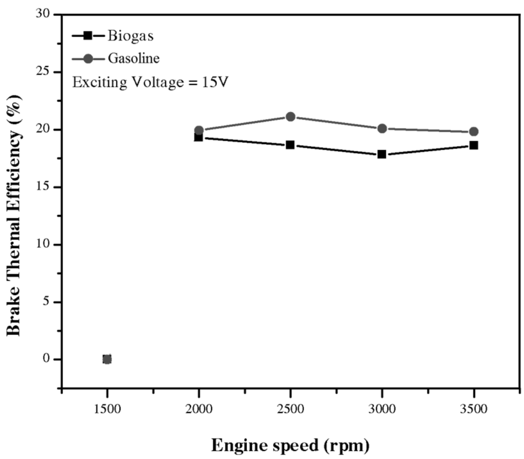

Fig. 9 Variation of thermal efficiency versus engine speed

3.1.5 Exhaust emission

Fig. 10 shows the variation of CO_2 with change of engine speed. It is clearly from the Fig. 10 that, at speed of 2500 rpm, CO_2 concentration of biogas and gasoline nearly the same, when speed increases from 1500 rpm to 3500 rpm, both CO_2 concentration for both cases increases, which concentration of CO_2 in exhaust of gasoline engine increases faster than that biogas engine cases. At speed of 3500 rpm, the concentration of CO_2 emission of biogas engine is lower than gasoline case about 1.1 times. Event through, the availability of CO_2 in biogas composition, the burning of biogas-air mixture generates still less CO_2 than the burning of gasoline-air mixture because gasoline has higher hydrocarbon in composition (equivalent gasoline as C_8H_{18}). This result shows that the conversion of CH_4 into CO_2 in the combustion products of biogas-air is less than gasoline operation

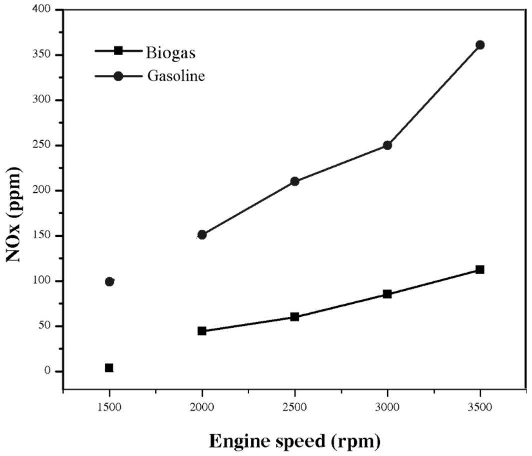

Fig. 11 Variation of concentration of NO_x with respect to engine speed for two cases

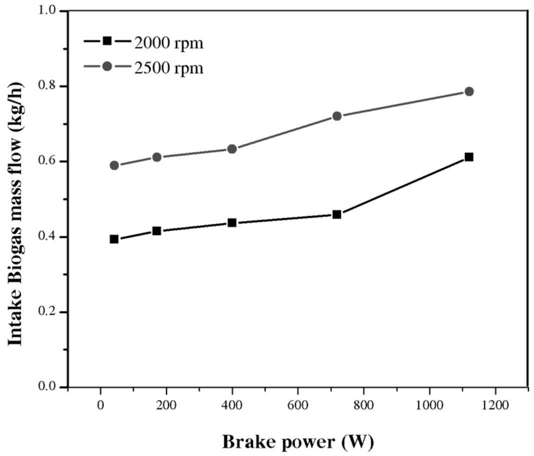

Fig. 12 Change of intake biogas mass flow with respect to brake power for two cases

and this contributes to reduce greenhouse gas effectively.

Fig. 11 shows when engine speed increase from 1500 to 3500 rpm, both concentrations of NO_x from exhaust of engine using biogas and gasoline increase, this is theoretically true for NO_x formation.

This is because at the higher speed under high load conditions, the combustion temperature is higher, this is a good condition to form NO_x emission and based on Fig. 11 the increasing of NO_x in engine using gasoline is higher than that in engine using biogas. The main reason is the combustion temperature of engine using gasoline is higher (with higher calorific value) than biogas case. In addition, high levels of CO_2 in the biogas reduced the temperature of burning biogas-air mixture.

3.2 Effect of load conditions

3.2.1 Biogas mass flow

Effect of load (brake power) on the variation of biogas mass flow is shown in Fig. 12. When load increases, the amount of biogas increases linearly. At each point of load, higher engine speed, higher biogas mass flow due to higher volumetric efficiency.

3.2.2 Brake specific fuel consumption (BSFC)

Fig. 13 shows the change of BSFC with respect to load for two different speeds. As shown in figure, the amount of biogas supply at speed of 2500 rpm is higher (about 1.2-1.5 times) than that of 2000 rpm. This may be caused by the increase of volumetric efficiency at high speed. Also, when engine load

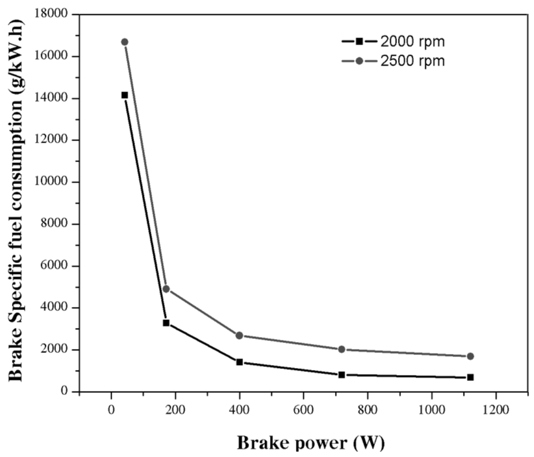

Fig. 13 Change of BSFC with respect to load

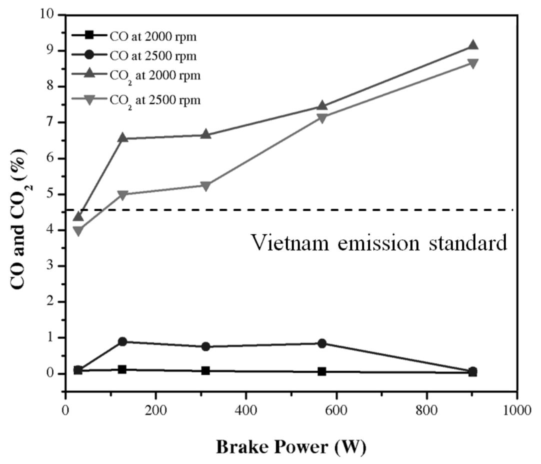

Fig. 14 Effect of system load on concentration of CO and CO_2

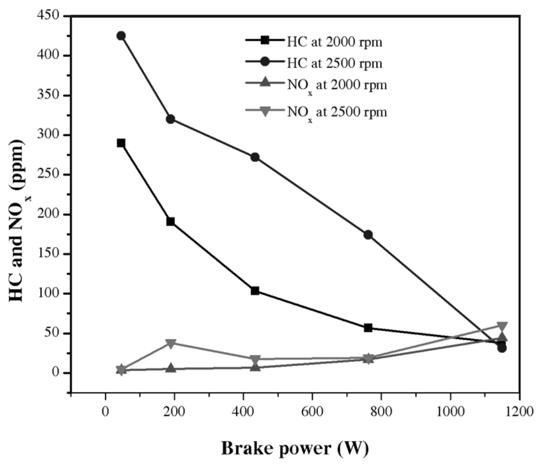

Fig. 15 Effect of system load on concentration of HC and NO_x

increases, BSFC decreases.

3.2.3 Exhaust emission

Fig. 14 shows the variation of CO and CO2 with change of load conditions. It is clear that CO emissions for both cases of engine speeds (2000 rpm and 2500 rpm) is less than 2% for biogas-air combustion. This is meet to the Vietnam emission standard for motorcycle (equivalence to EURO 2). Thus, if the suitable technologies for biogas storage with high energy density are developped, biogas can be operated in the motorcycle without any big abnormal problems.

In the figure, the CO emission is reduced for whole range of testing load because the conversion of CO into CO_2. For CO_2 emission, the increase of load leads to the increase of CO_2 emission. It is explained that when the engine load increases, the intake air (or oxygen) mass flow increase with increase of biogas mass flow. As a result, the formation of CO_2 from CO and oxygen occurred by the oxidation reaction. However, as mentioned above in Fig. 10, the CO_2 emission from biogas-fueled motorcycle engine is less than that of gasoline-fueled motorcycle engine. Thus, the application of biogas as a fuel for motorcycle engine is proper to the viewpoint of energy saving and the environmental protection.

Effect of load conditions on concentration of HC and NO_x was shown on Fig. 15. Engine operates at high speed and brake power, combustion process take place difficultly, with existing of unburned gas (CO_2, H_2S).

Combustion at speeds of 2500 rpm is less than combustion at speeds of 2000 rpm, lead to HC produced more. When brake power increase, combustion temperature increases also and so concentration of NO_x increases. The composition HC is higher at idle speed and decreases as brake power increase but maximum level of HC is less than 1200 ppm. It could meet the Vietnam national emission standard.

4. Conclusions

Performance characteristics of a motorcycle engine using biogas are estimated and compared with using commercial gasoline (Octane number: 92). The findings are:

1) Biogas-fueled motorcycle engine has higher fuel consumption than that of gasoline for the same operating conditions.
2) For the same load conditions with gasoline engine, BSFC of biogas engine is higher (around 1.75 times) while engine thermal efficiency is lower.
3) Exhaust emissions of biogas motorcycle engine is low. Increasing load or engine speed, concentration of NO_x and CO_2 in emissions increases, but not significantly. For biogas case, concentration of NO_x and CO_2 is the highest at speed of 3500 rpm, respectively less than 200ppm and less than 10%. Besides, the highest concentration of HC at idle-mode less than 500ppm and concentration of CO less than 1% that can meet the emission standards of Vietnam (Decision No. 249/2005/QD-TTg regulations the applicable emission standards for vehicles, at idle mode, limits of motorcycle engine HC is <1200 ppm and CO was <4.5%).

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