ANALYSIS AND COMPARISON ON EFFECT OF AIR-FUEL RATIO TOWARDS THE FOUR-STROKE SINGLE CYLINDER ENGINE PERFORMANCE

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ABSTRACT

The present study focuses on the effect of different air-fuel ratio (AFR) toward the four-stroke 150cc single cylinder piston engine power output. AFR is the mass ratio of air to fuel present in a combustion process such as in an internal combustion engine. The AFR is an important measure for anti-pollution and performance-tuning reasons. If exactly enough air is provided to completely burn all of the fuel, the ratio is known as the stoichiometric mixture, often abbreviated to "stoich". AFR numbers lower than stoichiometric are considered "rich". Rich mixtures are less efficient, but may produce more power and burn cooler, which is kinder on the engine. AFR numbers higher than stoichiometric are considered "lean." Lean mixtures are more efficient but may cause engine damage or premature wear and produce higher levels of nitrogen oxides. In theory, a stoichiometric mixture has just enough air to completely burn the available fuel. In this experiment, the main point of the study is to collect the data of the Yamaha Y15ZR engine performance with the various value of AFR by carry out the test using dynamometer laboratory. Engine performance is evaluated based on their horsepower and torque that are produced by the engine. Good engine performance result is generated from good adjustment of AFR, ignition timing and engine setup. During the dynamometer test, there are several adjustments needed to be conduct such as, amount of fuel injection, air screw and any other adjustment to achieve the set value of AFR by tuning it on programmable engine control unit (ECU). The AFR value is based on Lambda Oxygen (O_2) sensor in exhaust manifold. The result had been taken during dynamometer test by taking the record on horsepower, torque, carbon monoxide (CO), carbon dioxide (CO_2) and exhaust air temperature. The difference between the highest engine power output compare to the stoichiometric mixture power output is 3.3 horsepower gain. This makes a significant difference to the performance of the engine also consume less throttle compare to the stoichiometric mixture. This is because the rider just slightly open small amount of throttle to get the desired power. According to the tuner found that the throttle response of using AFR 12.5:1 is much better compare to the stoichiometric ratio.

Keywords: Air–fuel ratio, Engine performance, Cylinder pressure, Torque, Fuel consumption

1. INTRODUCTION

Engines burn fuel to create motions. The mixture of fuel with oxygen in the air causes the burning of fuel. This is called air-fuel ratio (AFR). AFR is the mass ratio of air to fuel present in an internal combustion engine. For petrol engines, the stoichiometric, AFR is 14.7:1, which means 14.7 parts of air to one   part of fuel. It depends on type of fuel. Different fuel gives different AFR. The AFR is necessary for controlling emission and performance-tuning reasons. The AFR widely applied in internal combustion engine for stoichiometric or leaner mixture which the ratio is 14.7:1 and above. The AFR which has been set by manufacturer for any commercial vehicle is using stoichiometric or leaner mixture, to get lower fuel consumption. Normally, the stock engine control unit (ECU) of any commercial vehicles are non-programmable which is the program inside the ECU is unable to tuning to avoid any undesirable events because of wrongdoing by people who are not qualified. The finding of this study will redound to the benefit to tuner and vehicle user considering that the AFR plays an important role for the performance of the vehicle throughout the world. The different type of AFR mixture does influence the power output of an engine and the knowledge of AFR that can be used for a long period of time to student and also lecturers for educational purposes. Thus, whoever that apply the recommended approach derived from the result of this study will be able to learn and train better.

Lean petrol mixture produces the best economy around 16:1 AFR, but the extra heat oxidizes. Air-borne nitrogen increases air pollution but low levels of CO. Leaning the mixture further past this point creates lean misfires with the mixture not burning completely. The levels of hydrocarbon begin to rise as unburnt fuel exits exhaust and power decreases. The Stoichiometric ratio of 14.7:1 can be seen on the chart which provides a good compromise between power, economy and emissions [1]. The increase of content of CO_2 in the atmosphere is one of the major causes of the greenhouse effect. CO_2 is a non-toxic product of combustion. The maximum values of carbon dioxide are reached in the area of stoichiometric ratio and these are approximately 14.7 of content %. CO_2 value has a high explanatory value about the engine condition and condition of its parts. The low values of CO_2 as well as the low values of CO and HC indicate the exhaust system leakages. In the case of catalyst proper function, CO_2 value can be even higher than when complete combustion [2].

In theory, a stoichiometric mixture has just enough air to completely burn the available fuel. In practice, this is never quite achieved, due primarily to the very short time available in an internal combustion engine for each combustion cycle. Most of the combustion process completes in approximately 4–5 milliseconds at an engine speed of 6,000 RPM. (100 revolutions per second; 10 milliseconds per revolution) This is the time that elapses from when the spark is fired until the burning of the fuel–air mix is essentially complete after some 80 degrees of crankshaft rotation. A rich mixture for petrol is a fuel/air mixture containing an excessive proportion of fuel. It may be desirable under certain operating conditions, such as when the engine is under load and provides enough fuel to use up all of the oxygen in the cylinder. Rich mixtures are cooler, but increased emissions of hydrocarbons due to unused excess fuel. Nitrogen oxides are low from the cooler temps, but the lack of free oxygen to convert CO to CO_2 makes CO much higher. Lean mixture for petrol is around 16:1 AFR produce the best economy, but the extra heat oxidizes. Nitrogen in the air increasing air pollution, but with low CO levels. Leaning the mixture further past this point creates lean misfires with the mixture failing to completely combust (and therefore NOx levels) [3].

To calculate the λ, simply divide the actual AFR by the Stoichiometric AFR. Lambda is equal to 1.00 exactly at stoichiometric mixture and increases as the AFR get leaner. For the best power, it has been found that somewhere between 13.2 to 13.4:1 (λ= 0.95) is ideal. For best economy, the AFR is between 14.7 to 15.5:1 (λ=1.05). The AFR of an engine can be measured by a Lambda Sensor in the exhaust gasses. Also known as an Oxygen Sensor. Currently most automotive manufacturers calibrate for rich AFR at wide open throttle which produces lower exhaust gas temperatures. Future federal emissions regulations may require less enrichment under these conditions [4]. This study was undertaken to address the question of what happens to engine power output with different AFR at wide open throttle. Tests were run on a single cylinder engine with a four-valve combustion chamber at a compression ratio of 10.4:1. The test matrix included several AFR at wide open throttle. The exhaust air must be sampled, and engine power output were recorded. The analysis provided data that different AFR produced different power output.

Running at wide open throttle (WOT) provides a valuable baseline to monitor the engine's performance. Repeating the test later might show a decline in RPM or speed, or an increase in temperature. Any change in performance points to a change in conditions, and one of those conditions might be the health of the engine. The basic process for WOT tuning is much like part throttle tuning. The primary difference is that the target AFR is usually much richer than stoichiometric.

2. METHODOLOGY

In this project data collected when the various values of AFR generate the data of horsepower, torque, CO, CO_2 and exhaust air temperature of Yamaha Y15ZR. The results of this test are taken during the dynamic test. Equation used in determine the horsepower (HP) and newton meter conversion parameters shown as below:

$$\text{Horsepower (HP)} = \frac{watt}{746} \qquad \text{(Equation 1)}$$

$$\text{Nm} = \frac{ft\ lb}{0.73756} \qquad \text{(Equation 2)}$$

Before experimental is begin, the pre checking must be done to the engine to ensure all data recorded are accurate. It is important to make sure all analysis is based on accurate and genuine data. Any not accurate data will affect the output of the experimental project. The main checking including the compression test; valve clearance (0.10mm exhaust valve clearance, 0.10mm intake valve clearance); testing on electronic tools such as coolant temperature sensor, radiator fan relay, and O_2 sensor; as well as checking on the condition of lubricant system, ignition system, cooling system, battery and charging system (alternator).

The test subject needed to be test immediately by the tuner. If the test subject is not well maintained, or mishap happened, the test subject needed to undergo maintenance for the test to get the actual reading. Below shows the sequence of conducting wide open throttle (WOT) tuning process for chassis dynamometer test:

- The test begins when the all the equipment is in good condition. Engine started and required for warm-up session for about two minutes.

- As the warm-up session completed, accelerate the motorcycle until fourth gear which is the transmission ratio is 1.0.

- Adjust the air and fuel mixture at 0 – 30% throttle position to stoichiometric mixture which is 14.7:1 AFR.

- Adjust the air and fuel mixture at 30 – 50% throttle position to 14:1 AFR.

- Adjust the air and fuel mixture at 50 – 70% throttle position to 13.5:1 AFR.

- After the air and fuel mixture at 0 – 70% throttle position was set, then the different AFR been test at 70 – 100% throttle position. The AFR tested is 15.0:1, 14.7:1, 14.0, 13.5:1,13.0:1, 12.5:1 and 12.0:1

- Take a record on horsepower, torque during wide open throttle process.

- Take a data of CO, CO_2 and exhaust air temperature at 8000 RPM by using Kane 250 flue gas analyzer.

3. RESULTS AND DISCUSSION

Table below shows the research collecting data table. It is including the date of data recorded, bore and stroke dimension, type of fuel used, humidity, air temperature and amount of cylinder.

Table 1: Dynamometer Test Result

Humidity: 64%		Bore x stroke: 57mm x 58.7mm			Fuel type: Shell Unleaded RON97	
		Air temp: 27 °C			Cylinder: 1	
AFR	Horsepower (HP)	Power gain/ loss (HP)	Torque (Nm)	CO (%)	CO_2 (%)	Exhaust air temperature (°C)
12.0:1	18.9	3.0	21.28	8.72	9.30	131
12.5:1	19.2	3.3	19.38	6.98	10.39	133
13.0:1	19.0	3.1	19.79	5.24	11.48	132
13.5:1	18.7	2.8	21.55	3.50	12.57	134
14.0:1	18.3	2.4	21.00	1.76	13.66	133
14.7:1	15.9	0	18.53	0.00	14.76	136
15.0:1	14.4	-1.4	12.67	0.02	11.53	139

From the table above, it also shows the result of various AFR mixture on Yamaha Y15ZR toward horsepower, power increment, torque, CO, CO_2 and exhaust air temperature. In addition, the data of CO, CO_2 and exhaust air temperature is recorded at 8000 RPM by using Kane 250 flue gas analyzer.
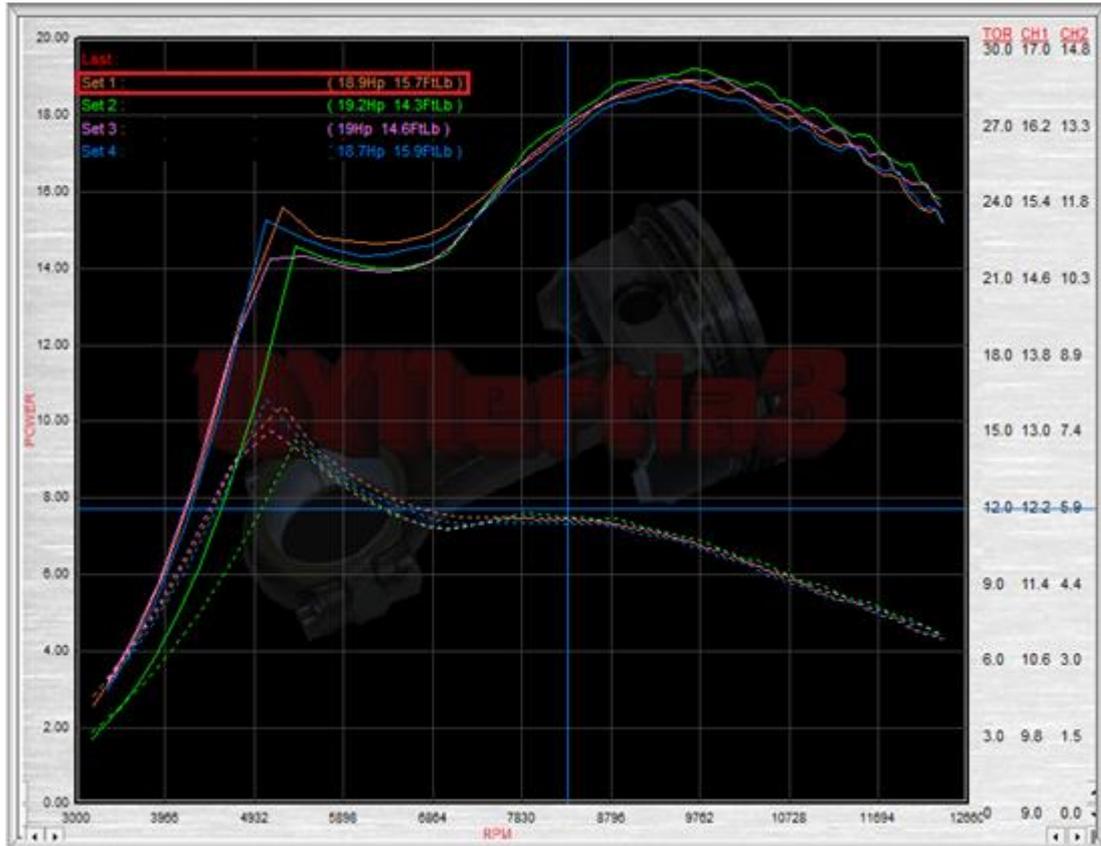
Figure 1: Result of power output at AFR 12.0:1

Figure above showed that the highlight engine power output at AFR 12.0:1 is 18.9 horsepower. There 3 horsepower gain compare to the stoichiometric mixture. Starting at this point where the power start to drop if the amount of fuel is added. Thus, there is no point of adding more fuel beyond this point. In this figure also showed, the torque produced on this mixture is 15.70 ft.lb or 21.28 Nm.
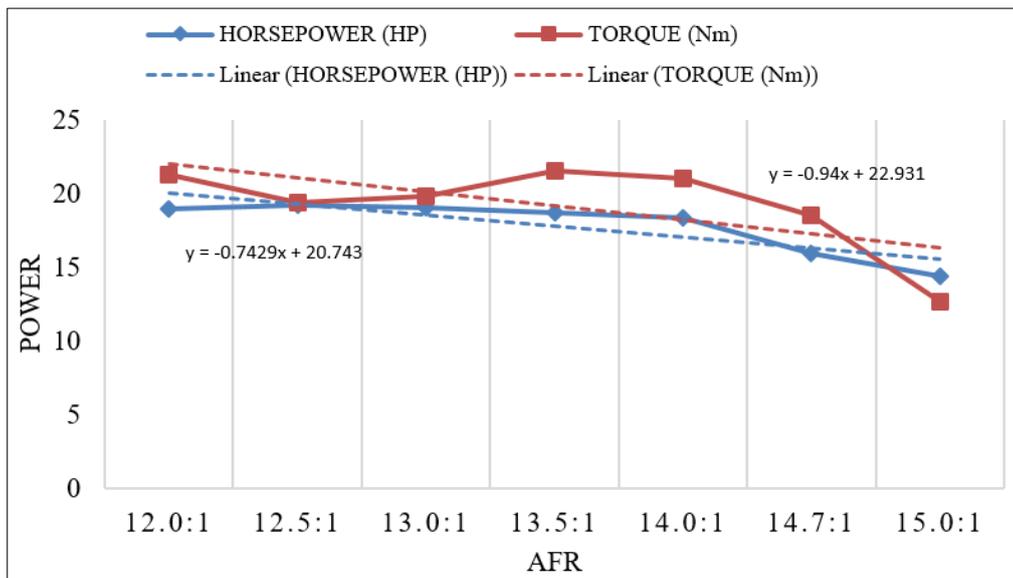

Figure 2: Effect of AFR towards power and torque

Figure above showed the result for horsepower and torque on every various of AFR. As the AFR has been set to stoichiometric, the power output value is recorded. Thus, starting from stoichiometric mixture to rich mixture. As the AFR decrease, the amount of horsepower and torque increased. Thus, the AFR is proportional to the power output of the engine. Then after a certain AFR value, the power output stop increased. This point was noted and is the maximum range for that specific AFR.

Based on figure, it is clearly showed that the AFR 12.5:1 produced the highest power and for highest torque is located on AFR 13.5:1 which is 21.55 Nm compare to others AFR. Usually the AFR for maximum power is between 12-13:1, depending on how well the vapor was previously mixed [5]. In this study, the highest horsepower is located on AFR 12.5:1. According to the tuner found that the throttle response of using this AFR is much better compare to the stoichiometric ratio. This proves that the peak horsepower is between AFR 12-13:1 for petrol engines. Besides, the trend of horsepower descent when the AFR is increase because of lack of fuel in combustion. Besides, AFR from 12.0:1 to 13.5:1, we can see the output power is almost the same with each other. Only a slight change in power.

The result showed that when the fuel is added after the AFR 12.5:1, the engine horsepower starts decreases. It is because of too much & unburnt fuel in the combustion. It makes the combustion not achieve the maximum explosion inside the combustion chamber. Thus, there is no point of adding more fuel beyond this point. However, the richer AFR especially in forced induction engines where the excess fuel is used to cool combustion and so prevent detonation [6].

In this figure also showed, the highest torque compares to others mixture produced on AFR 13.5:1 which is 15.90 ft.lb or 21.55 Nm. It is because in the engine operating range from peak torque to peak power, a naturally aspirated engine should be slightly leaner at about 13 – 13.5:1, with the forced induction factory engine about 12:1 and an aftermarket supercharged engine staying at about 11:1 ratio [6].

Lastly, for the lowest horsepower and torque in this study is located on AFR 15.0:1. Commonly, any commercial vehicle is using stoichiometric or leaner mixture, to get lower fuel consumption. It is better for the economy to run lean. It used all the fuel injected by having an excess of air when it comes to economy. Free oxygen in the cylinder will be wasted but avoiding waste of fuel is the priority for an economic tune. Lean mixtures are more efficient but may cause engine damage or premature wear and produce higher levels of nitrogen oxides. A drawback of using stoichiometric or leaner mixture is it will limit the full performance of the engine that supposed to produce higher horsepower output during the acceleration [7].
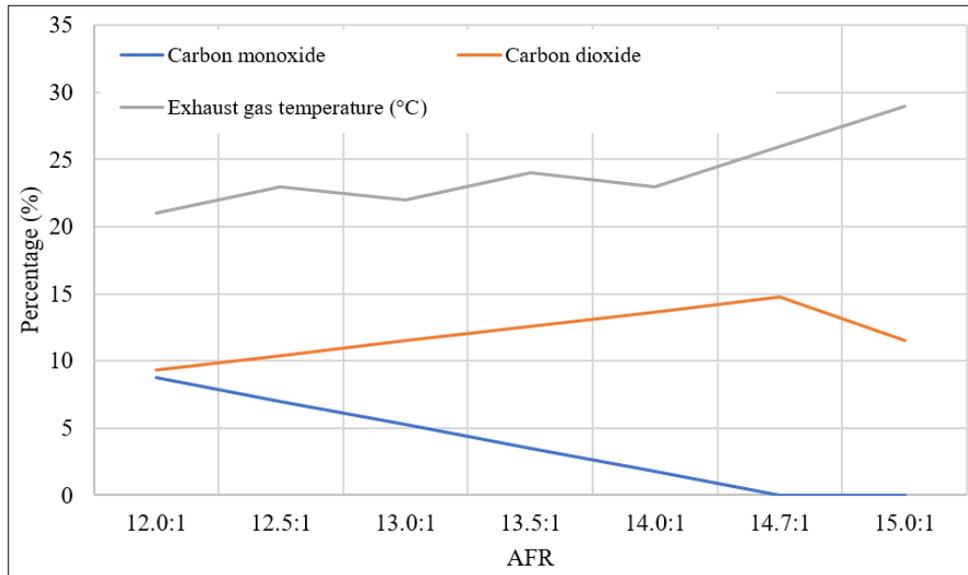
Figure 3: Effect of AFR towards CO, CO2 and exhaust gas temperature

Figure above shows the result of exhaust gas on every various of AFR mixture. The result shows, AFR 14.7:1 and 15.0:1 contains 0 percent of CO. While after increment the fuel mixture, the value of CO rapidly increases proportionally to the AFR. This mean start from 14.6:1 until 12.0:1 it starts produced CO from the combustion. CO is a colorless and odorless gas which is initially non-irritating. it is produced during incomplete burning of fuel inside the combustion chamber. Based on other related research, CO emission from lean burn in motorcycle engine found the CO emissions drop sharply when AFR changed from rich to lean [8].

Based on figure above, the peak amount of CO_2 produced on AFR 14.7:1 which is 14.76 %. CO_2 emissions impact human health by displacing oxygen in the atmosphere. Breathing more difficult as CO_2 levels rise. In closed areas, high levels of CO_2 can lead to health complaints such as headaches. The maximum values of CO_2 are reached in the area of stoichiometric ratio and these are approximately 14.7 of content %. CO_2 value has a high explanatory value about the engine condition and condition of its parts.

According to the result of exhaust air temperature, the temperature it slightly decreases when the AFR is decrease. It is because, the excess fuel is able to absorb heat and cool the temperature inside the combustion chamber. Actually, the amount of heat produced had been filtered and cooled by exhaust catalyzer. it caused decrease the heat and gasses from the actual reading. According to Ceviz, combustion temperature may be reduced by using fuel rich mixtures to limit the amount of oxygen available, injecting cooled oxygen-depleted flue gas into the combustion air to dilute energy, injecting cooled flue gas with added fuel or injecting water or steam [9].

4. CONCLUSION

Analysis and comparison on the effect of air-fuel ratio towards the four-stroke 150 cc single cylinder engine performance has been conducted through this study. The objectives of this project were completely achieved. The first objective had been achieved by determine the effect of AFR toward Yamaha Y15ZR engine power output and measure the presence of CO, CO_2 and air temperature on exhaust manifold output. The data of the Yamaha Y15ZR had been collected based

on engine horsepower and torque with the various variable value of AFR by carry out the test using dynamometer laboratory. The data of CO, CO_2 and exhaust air temperature is recorded at 8000 RPM by using Kane 250 flue gas analyzer.

Next, the second objective of this project is to compare the horsepower and torque obtain from the various test at the dynamometer laboratory with the stoichiometric mixture test result. After the experiment carried out, the objective is achieved according to plan. This experiment found that the engine power output slightly increased when the AFR getting richer from stoichiometric mixture. Until the certain air fuel mixture, the power stop increasing. Thus, found the highest engine power output which is 19.2 horsepower at AFR 12.5:1. While for highest torque is located on AFR 13.5:1 which is 21.55 Nm compare to others AFR.

Last but not least, from the experiment, the difference between the highest engine power output compare to the stoichiometric mixture power output is 3.3 horsepower gain. This makes a significant difference to the performance of the engine also consume less throttle compare to the stoichiometric mixture. This is because the rider just slightly open small amount of throttle to get the desired power. According to the tuner found that the throttle response of using AFR 12.5:1 is much better compare to the stoichiometric ratio.

This experiment can be developed in many ways as it is a data collection. Many methods can be use besides using chassis dynamometer. Dynamometer development such as brake dynamometer, motoring dynamometer and more can be done using different method. The test facility which is the chassis dynamometer do not have the braking force which can create a real riding situation. The brake dynamometer applies variable load on rear wheel to create the real riding load. Thus, obtain more accurate reading of the engine power output.

Measuring device used is also important to collect the accurate data. It must have an accurate and specific purpose. For this experiment, the device used is Kane 250. It is specific purpose for burner on a boiler or any related equipment. The recommended device to be used for more information and accurate reading, it is recommended to use model 7466-Rugged Portable Analyzers for engine exhaust emissions, which is more specific for the petrol combustion engine. This device potentially to measure the presence of HC, NOx, O_2, AFR, RPM, flue temperature, CO and CO_2 which is more information compared to Kane 250.

REFERENCES

[1] C. D. Gaonkar, D. R. Rao, K. M. Kumar *et al.* (2020) End corrections for double-tuning of the same-end inlet-outlet muffler. Publisher Edition ed: p. 107116. doi: https://doi.org/10.1016/j.apacoust.2019.107116

[2] Branislav Sarkan, Ondrej Stopka, Jozef Gnap *et al.* (2017) Investigation of exhaust emissions of vehicles with the spark ignition engine within emission control. Publisher Edition ed: pp. 775-782. doi: https://doi.org/10.1016/j.proeng.2017.04.437

[3] Fredrik Königsson, "Advancing the limits of dual fuel combustion," KTH Royal Institute of Technology, 2012.

[4] Edward W Kaiser, M Matti Maricq, Ning Xu *et al.* (2005) Detailed hydrocarbon species and particulate emissions from a hcci engine as a function of air-fuel ratio. Publisher Edition ed: pp. 1404-1414.

[5] James M Sevik, Thomas Wallner, Scott Miers *et al.*, "Air-to-fuel ratio calculation methods for oxygenated fuels in two-stroke engines," SAE Technical Paper, 0148-7191, 2015.

[6] Tan Tien Huynh, Minh Duc Le, and Dinh Nghia Duong (2019) Effects of butanol–gasoline blends on si engine performance, fuel consumption, and emission characteristics at partial engine speeds. Publisher Edition ed: pp. 483-492. doi: 10.1007/s40095-019-0309-9

[7] Mm Rahman, Mohammed K Mohamme, and Rosli %J Journal of Applied Sciences A Bakar (2009) Effects of air-fuel ratio and engine speed on performance of hydrogen fueled port injection engine. Publisher Edition ed: pp. 1128-1134.

[8] Banglin Deng, Qing Li, Yangyang Chen *et al.* (2019) The effect of air/fuel ratio on the co and nox emissions for a twin-spark motorcycle gasoline engine under wide range of operating conditions. Publisher Edition ed: pp. 1202-1213.

[9] George V Last and Mary T Schmick, "Identification and selection of major carbon dioxide stream compositions," Pacific Northwest National Lab.(PNNL), Richland, WA (United States), 2011.