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COMPUTATIONAL INVESTIGATIONS ON THE PERFORMANCE AND EMISSIONS CHARACTERISTICS OF RANGE EXTENDER SPARK IGNITION ENGINE FUELED WITH BIOGAS APPLIED FOR SMALL ELECTRIC VEHICLES

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Abstract

This paper presents a study about design and simulation test on performance of range extender-based spark ignition engine fuelled with biogas applied for small electric vehicles which appropriate for developing countries, where the charging station infrastructures are limited. The study was conducted firstly by designing a two cylinders range extender-based spark ignition engine for 35 kW of electric vehicle. To analyse the performance and emission behaviours of the engine, a simulation study using AVL BOOST was conducted with variation of gasoline-biogas fuels blend from 0 to 100 % by volume. The results showed that engine indicated mean effective pressure, power, and indicated efficiency decrease correspond to the biogas content in fuel. The nitrogen oxide emission of range extender spark ignition engine was decreased when using higher content of biogas, but the emissions of hydrocarbon and carbon monoxide were increased. Anyhow, the range extender SI engine fulfils small electric vehicle needs which the charging power is at least 20 kW. Thus, the designed two cylinders engine can be operated using biogas fuel and the performance fulfil the requirement.

Keywords: Biogas engine, Charging station, Distance anxiety, Range extension, Small electric vehicles.

1. Introduction

Nowadays, various efforts and strategies are being managed to reduce fossil fuel utilization and decrease dangerous exhaust emissions in the vehicle industry. Some examples of the energy converters apparatus that have high efficiency and produce low emissions have been suggested by many researchers [1-3]. Electric Vehicles (EVs) has been proven as one of the environmentally friendly methods with no emissions while operating on road, although the 40% of worldwide carbon dioxide emissions are contributed from electricity generation source [4]. However, EVs also have many problems behind the extraordinary advantages, such as the short mileage because of small density of the amount of battery energy, charging that takes a relatively long time, a few of charging stations and facilities and the other disadvantages [5]. To solve these problems of EVs, the Range-Extended Electric Vehicle (REEV) is introduced [6].

In principle, the range extender system is a generator set which is operated for charging when the electric vehicle's battery has lack of power [7]. It is exclusively arranged for refilling the power to the battery and separated from vehicle shaft. Basically, almost all power converters could be applied as a range extender, for instance the fuel cell, internal combustion engine (ICE), and micro gas turbine (MGT), etc. Table 1 shows the comparison of range extender powered with ICE, MGT and fuel cell [2, 8, 9]. The ICE has disadvantages of efficiency, power density, and noise, vibration and harshness (NHV) when compared with fuel cell and MGT. However, it has benefits in production cost and scalability. While the ICE efficiency can be improved by modifying some conditions such as reducing engine speed, reducing displacement or changing compression ratio, and boosting through turbocharging or supercharging, etc. [10]. Small production cost usually followed by easier and cheaper maintenance cost. It is also supported with high possibility for the flexibility of fuel. Therefore, the ICE still could be the most potential range extender for EVs especially in developing countries with rural and remote area characteristics and also abundant renewable energy resources such as Indonesia.

Table 1. Comparison of range extender powered with ICE, MGT and Fuel cell.

Characteristics	ICE	MGT	Fuel cell
Efficiency	19 – 31 %	25 – 35 %	Up to 59%
Density of Power	0.16 – 0.45 W/kg	400 W/kg	200-885 W/kg
Production cost	27 – 35 $/kW	350–500 $/kW	650 – 780 $/kW
Emissions	Required exhaust catalyst	NOx 9 ppmv, CO 50 ppmv (using natural gas) NOx 35 ppmv, CO 15 ppmv (using fluid fuel)	H_2O and a little H_2
Variation of fuel	Yes	Yes	No
NVH	Silent	Silent	Very Silent
Scalability	Good	Mid-good	Mid-good

Several range-extender studies already have been presented on these past few years, showing spark ignition engines as the main energy converters. A study on 1-cylinder 2-stroke spark ignition engine for range-extender was conducted earlier [11-13]. It is found that there are wide ranges for more ignition enhancements, exploring the possibility of direct injection, and the variation of the piston shape. The other study about comparison of a range extender fuelled with LPG and gasoline has been presented by Lasocki et al. [14]. The results showed the suitability of LPG to be applied as fuel for range extender. Its fuel burning and efficiency of thermal were also at a similar value to those resulted for gasoline fuel, but with smaller carbon dioxide of exhaust emission. The attractive solution for range extender with simplest ICE configuration, which is the single cylinder engine, was proposed by Friedl et al. [15]. The concept is to bring components collectively into the extensively from motorcycle or power-products for the application of EVs range extenders. The starting requirement of a range extender for EVs based on a 4-stroke small engine was already studied [16]. The study explained that range extenders of lighter than 25 kg can be designed with an engine volume of 150 to 200 cm^3 to adapt the availability and the important of space and weight.

Previous studies for the ICE-SI range extender of EVs mostly focused only on the analysis of efficiency and its comparison with the others power converters such as fuel cell and MGT [13, 14, 16]. Which will increasingly show the shortcomings of ICE for range extender. However, a breakthrough concept such as the application of alternative or biofuel such as biogas for range extender SI engine rarely conducted [13, 14, 16]. Therefore, comprehensive research is required to explore the application of biogas as a substitute fuel for range extender SI engine. Furthermore, to find out how the engine performance and the operating conditions. Many benefits will be obtained by applying biofuels such as biogas which content majority methane gas to range extender engine especially for developing countries where the EVs charging infrastructure is limited. The applications of methane on ICE have been studied and explained the advantageous previously [17-22]. Thus, this paper presents computational studies on the performance and exhaust emissions behaviours of range extender spark ignition-based engine fuelled with biogas applied for small electric vehicles. The purpose of this study is to simulate the operation of a range extender spark ignition engine, which appeared without modification in the ICE specification, and only shifting their working parameters, applying biogas as the main fuel and the blending of various percentages by volume of gasoline as reference fuel.

2. Research Method

2.1. Designing and prototyping of range extender spark ignition engine for 35 kW electric vehicles

Since 2005, Indonesian Institute of Sciences (LIPI) concerns on the research and development of EVs to comply Indonesia domestic needs. In 2008, a prototype of 35 kW series hybrid electric vehicles as can be seen in Fig. 1, was created and still being improved until now (2020). The schematic diagram of LIPI's series hybrid electric vehicles can be seen in Fig. 2. Currently, LIPI focused to develop a range extender spark ignition engine for the HEVs which can be fuelled with biogas resulted from local agriculture plantation or farm at rural or remote area. The range extender is an assistance power source, which used not to provide the full of vehicle power requirement, thus the size of the range extender can be designed relatively small. Based on this condition, it was decided that the output target of the required range extender at least 20 kW. Then a design and prototype of range extender engine with a power of 20 kW swept volume 999 cc was created as can be seen in Fig. 3. While the engine specifications can be seen in Table 2. To understand the performance and exhaust emissions characteristics of the engine a numerical test then was conducted due to some restriction for real test experiment.

Specifications:

- Motor: 3 Phase Induction 72 Volt AC
- Engine: 160cc/gasoline
- Generator: 1-Phase AC 2.2 kVA
- Controller: 550 A, 72 Volt AC
- Speed: 80 km/h;
- Charging: input 220 VAC, output 72 VDC / 40 A
- Battery: Lithium Battery (Life PO4), 72 Volt/200Ah, @2.8V-4.0/200Ah

Fig. 1. LIPI's hybrid electric vehicles.

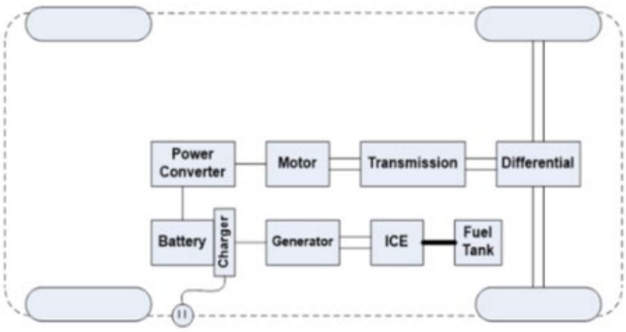
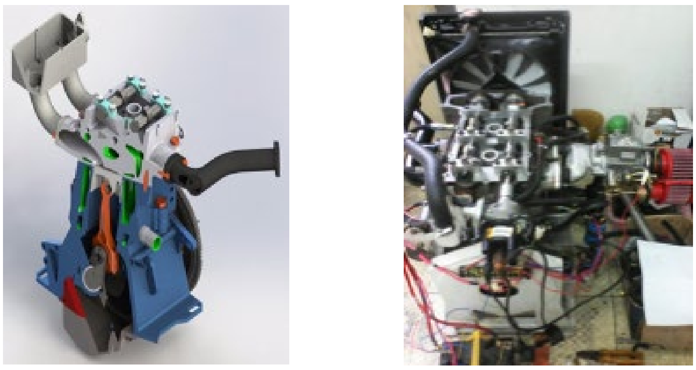


Fig. 2. Schematic diagram of LIPI's series hybrid electric vehicles system.



(a) Design of LIPI's range extender engine. **(b) Prototype assembly of LIPI's range extender engine.**

Fig. 3. Design and prototype of range extender engine with a power of 20 kW swept volume 999 cc.

Table 2. Specification's design of LIPI's range extender engine.

Parameters	Value
Engine Type	Spark Ignition
Displacement	999 cc
Working Temperature	80°C
Number of Cylinder	2
Number of Stroke	4
Bore x Stroke	86 mm x 86 mm
Maximum Speed	6000 rpm
Idle Speed	1500 rpm
Maximum Torque	104.5 Nm (@3500 rpm)

2.2. Computational investigations procedure

The software used for the computational investigation was the AVL BOOST, which offers a graphical user interface (GUI) arranged of symbols that reflect parts of the engines. After selected and linked to each other, the reflective symbols enable to open windows whereby the engine geometry and operating data, including the mathematical formulas that develop the computational analysis are added [23]. The AVL Boost simulation model developed to express the range extender spark ignition engine is shown in Fig. 4 and Table 3 presents the terminology of the major components adopted in the simulation model and determined in Fig. 4.

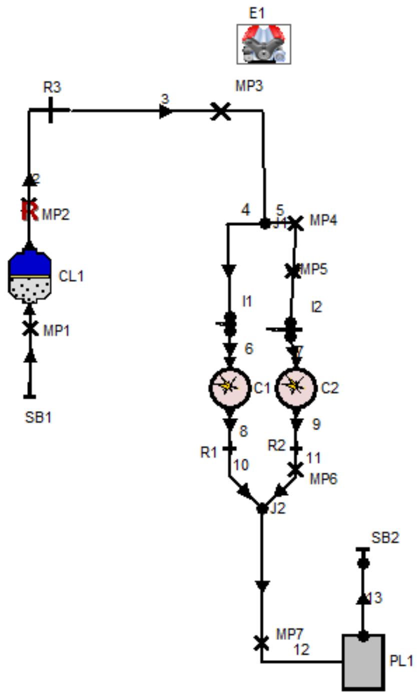


Fig. 4. Schematic arrangement of the simulation model of the range extender spark ignition engine.

Table 3. Terminology of the main components adopted in the simulation and determined in Fig. 4.

Item symbol	Components	Quantity
E	Engine	1
CL	Air Cleaner	1
SB	System Boundary	2
MP	Measuring Point	7
C	Cylinder	2
I	Injector	2
PL	Plenum	1
R	Restriction	3

The geometric information and operating conditions adopted to develop the computational simulation were imported from the range extender engine specifications data which were shown in Table 2. Where, the compression ratio was adjusted for 10.5.

2.2.1. In-cylinder combustion model

The combustion calculation model inside the cylinder adopted was Vibe Two Zone, which determines the heat release rate, regarding the burned and unburned mass fractions. Therefore, the computation of the thermodynamic state of the combustion chamber following the first law of thermodynamics, as follows:

$$\frac{dm_b u_b}{d\alpha} = -p_c \frac{dV_b}{d\alpha} + \frac{dQ_F}{d\alpha} - \sum \frac{dQ_{Wb}}{d\alpha} + h_u \frac{dm_b}{d\alpha} - h_{BB,b-\frac{dm_{BB,b}}{d\alpha}} \quad (1)$$

$$\frac{dm_u u_u}{d\alpha} = -p_c \frac{dV_u}{d\alpha} - \sum \frac{dQ_{Wu}}{d\alpha} - h_u \frac{dm_b}{d\alpha} - h_{BB,u-\frac{dm_{BB,u}}{d\alpha}} \quad (2)$$

where:

b and u = Burned and unburned zone;

$\frac{d(m.u)}{d\alpha}$ = Change of the energy in the chamber;

$-p_c \frac{dV}{d\alpha}$ = Work of piston;

$\frac{dQ_F}{d\alpha}$ = Heat input from fuel;

$\sum \frac{dQ_W}{d\alpha}$ = Heat loss to the wall;

$h_{BB.-\frac{dm_{BB}}{d\alpha}}$ = Blow-by enthalpy flow.

The formula $h_u \frac{dm_B}{d\alpha}$ comprises the enthalpy flow through the unburned to the burned zone because of the transformation of a fresh input to combustion products and heat flux between the two zones are ignored [24].

2.2.2. Scavenging computational model

The scavenging computational model regards the scavenging efficiency which is characterized as the volume of intake air into the combustion chamber related to the combustion chamber swept volume, and the delivery ratio which is determined as the total quantity of air which filled the combustion chamber related to the total combustion chamber swept volume. In considering this model, data were entered as shown in Table 4.

Table 4. Main input data in the simulation model of the combustion chamber.

Parameters	Value
Length of Con. Rod	143.5 mm
Mean crankcase pressure	0.1 MPa
Scavenge Model	Perfect Mixing

For the scavenging calculation, the basic model for four-stroke ICE of AVL BOOST was managed. The basic model consists of Perfect Mixing model, which counts that the gas coming into a combustion chamber is instantly mixed with the charges of the combustion chamber, and the gas discharging a combustion chamber has the similar configuration as the mixture of the combustion chamber [24].

2.2.3. Heat transfer computational model

The computational model adopted and chosen in the AVL BOOST simulation lists for heat transfer from the combustion chamber to walls of the cylinder was Woschni (1978). The reason is that Woschni model has high accuracy based on AVL's experience and identical to SI engine's parameters assumption were used in this study, where concerned the heat flux from the working fluid to the cylinder wall, as showed by the following formula [24]:

$$\alpha_w = 130 \cdot D^{-0.2} \cdot p_c^{0.8} \cdot T_c^{-0.58} \cdot \left[C_1 \cdot c_m + C_2 \cdot \frac{V_D \cdot T_{c,1}}{p_{c,1} \cdot V_{c,1}} \cdot \left(p_c - p_{c,o}\right)\right]^{0.8} \tag{3}$$

where:

C_1 = 0.308 C_u/C_m + 2.28;

C_2 (DI) = 0.00324;

C_2 (IDI) = 0.00622;

D = Cylinder diameter;

c_m = Average speed of piston;

c_u = Circumferential velocity;

V_D = Swept volume of engine;

$p_{c,0}$ = Motoring cylinder pressure;

$T_{c,1}$ = Temperature in the chamber at intake valve closing (IVC);

$p_{c,1}$ = Pressure in the chamber at IVC.

2.2.4. Emissions simulation models

For the computation model of HC, CO and NOx construction basic models were used the available calculation defaults in AVL BOOST [24]. A comprehensive description of the HC development process cannot yet be given and definitely the achievement of a robust predictive model using a thermodynamic method is limited by the basic theory and the concern of reduced simulation times. However, the calculation of HC formation in AVL BOOST at least generally can be adopted from crevice mechanism, HC absorption/desorption mechanism, and partial burn effects. Finally, a simplified method to account for the HC formation process in BOOST has been proposed by Lavoie and Blumberg, using an Arrhenius formula which considers the slow HC post-oxidation. The CO formation model utilized in BOOST is based on Onorati et al. [25] model and involving 2 main reactions, involving 6 species. The NOx construction model in BOOST is following Pattas and Häfner model and including 6 main reactions based on the Zeldovich mechanism, involving 8 species.

2.2.5. Simulation methodology

The simulation method in this study is the Classic Species Transport option formula for burning products (together with the air fuel rate behaviour for them) and fuel vapour. The mass fraction of air is determined from:

$$W_{air} = 1 - W_{FV} - W_{CP} \quad (4)$$

where:

W_{air} = Air mass fraction;

W_{FV} = Fuel vapour mass fraction;

W_{CP} = Combustion products mass fraction.

The fuels used in this study were gasoline and biogas. The fresh biogas naturally produced form livestock, agriculture and plantations farm usually contains big portion of CH_4 and some impurities as shown in Table 5 [26]. However, the biogas fuel in this study is represented as high purity biogas after purifying process which mainly contains CH_4 or methane. Table 6 shows the properties of gasoline and CH_4. The simulation procedure to analyse the performance and emission behaviours of the engine was conducted with variation of gasoline-biogas fuels blend from 0 to 100 % by volume. The engine performance and emissions then evaluated including, IMEP, engine power, fuel consumption, engine efficiency, HC, CO and NO_x.

Table 5. Chemical properties of biogas.

Chemical Parameters	Content
CH_4	50 – 57%
CO_2	25 – 50%
N_2	0 – 10%
H_2S	0 – 3%
H_2	0 – 1%
O_2	0 – 0.5%

Table 6. The properties of fuels [27-30].

Chemical formula	Gasoline	CH_4
Molar weight	100–105 g/mol	16 g/mol
Boiling point	25–225°C	-164°C
LHV	45.86 MJ/kg	50.2 MJ/kg
Specific heat	2 kJ/kg K	2.889 kJ/kg K
Autoignition temperature	530 K	580 K
Density	712.7 kg/m^3	0.65119 kg/m^3

3. Results and Discussion

3.1. Results validation

After developing the simulation in AVL BOOST, the engine performance was validated with the experimental work by Hoag et al. [10]. The engine used in experiment has similar dimensions of bore and stroke with the engine used in simulation works, which is 86 mm × 86 mm. The validation technique was conducted by matching values of IMEP and indicated fuel specific consumption (IFSC) between simulation and the experiment results with only gasoline as a reference fuel. As it is known that the indicated mean effective pressure is not influenced by the engine speed. Also, since the torque is divided by the engine capacity, the indicated mean effective pressure parameter can be used to compare internal combustion engines even for different displacements. It is assumed when both of the experiment and simulation in the similar characteristics for gasoline fuel, as long as same engine parameters are used in simulation, then if there is a different value results by using the other fuels, meaning due to the effect of that the different fuels. Table 7 shows the validation results between simulation and experimental works [8]. There are two engine speed values as a basic comparison that are 2000 and 4000 rpm. For all of IMEP and ISFC there are no significant different values between simulation and experiment which mean the validity data of this simulation study is near to the experimental study.

Table 7. Validation data of simulation and experimental works.

Engine speed	Parameters	Value		Difference
		Simulation	Experiment	
2000 rpm	IMEP	1.29 MPa	1.30 MPa	0.76 %
	ISFC	230 g/kWh	216 g/kWh	6.08 %
4000 rpm	IMEP	1.42 MPa	1.45 MPa	2.06 %
	ISFC	229 g/kWh	221 g/kWh	3.49 %

3.2. Engine performance characteristics

Because of the operating of engine cycle, the pressure in the engine chamber changes dynamically. In order to predict the variation of pressure average value inside the engine chamber, mean effective pressure (MEP) criterion is determined. Because of every engine have their specific size and speed when operated, using MEP is the best way to evaluate performance of an engine compared with the other in terms of design and output. To define MEP value of the engine, indicated mean effective pressure (IMEP) is computed by using indicated work. In this study, the IMEP was used to determine the comparison of engine performance fueled with biogas and gasoline blends.

Figure 5 gives the simulation results about the variation of IMEP on engine with the utilization of biogas blended with gasoline from 0 to 100 % by volume at various engine speeds from 2000 to 5000 rpm. The results showed when the engine is operated with higher biogas content in the fuel, the IMEP value is decreased. This condition happened because of the effect of methane (CH_4) content in the biogas. As mentioned in the previous study [17] that more methane content in the fuel, the burning process is slower than any other of hydrocarbon species, furthermore the combustion is earlier with increasing of methane content, which can produce lower indicated mean effective pressure. As explained previously [17] lower methane content may cause the combustion period decreases and the maximum combustion pressure increases greatly. The other previous study [18] also explained that the lowest values of the peak working medium chamber pressure were found when the engine was fuelled by high concentration of methane. It is also having consequent to the engine power as depicted in Fig. 6. Biogas had lower brake power values, because of their low heating value by volume, less flame speed, and the small volumetric efficiency compared to the gasoline fuel [19]. However, as the range extender required power is at least 25 kW, the engine running with 100 % biogas still fulfills that requirement as long as the engine speed adjusted more than 3000 rpm.

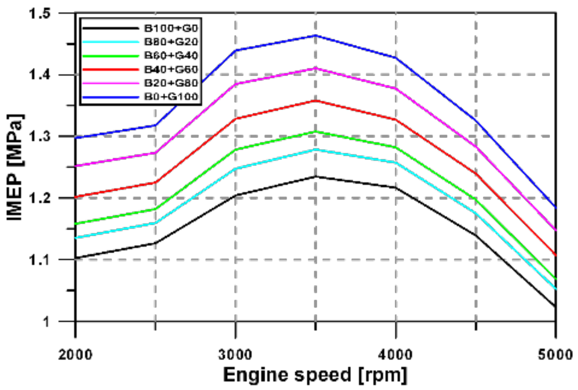


Fig. 5. Effect of biogas on IMEP of range extender engine.

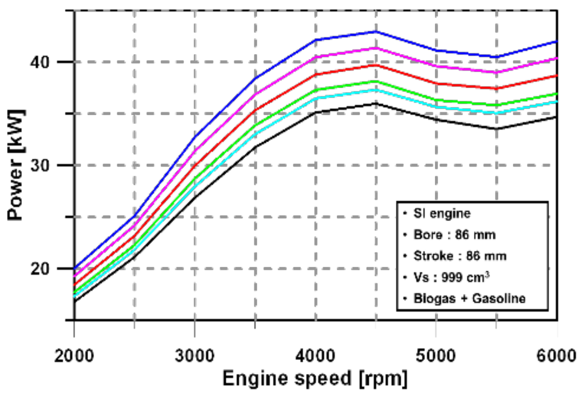


Fig. 6. Effect of biogas on power of range extender engine.

Indicated thermal efficiency and specific fuel consumption are used to evaluate the economy of the engine as can be seen in Figs. 7 and 8. The similar trend can also be seen for the indicated thermal efficiency. The indicated thermal efficiency of gasoline 100 % combustion achieves a maximum as the consequent of the decreasing of methane content [17]. It can be explained that the higher indicated thermal efficiency resulted from the increasing of combustion efficiency. The higher combustion efficiency leads to the better and economize fuel consumption. In this case lower methane content decreasing the brake specific fuel consumption.

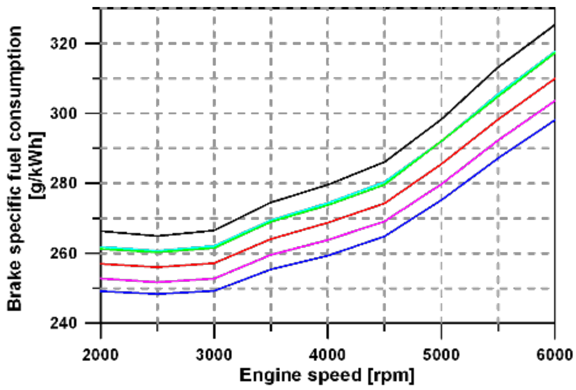


Fig. 7. Effect of biogas on brake specific fuel consumption of range extender engine.

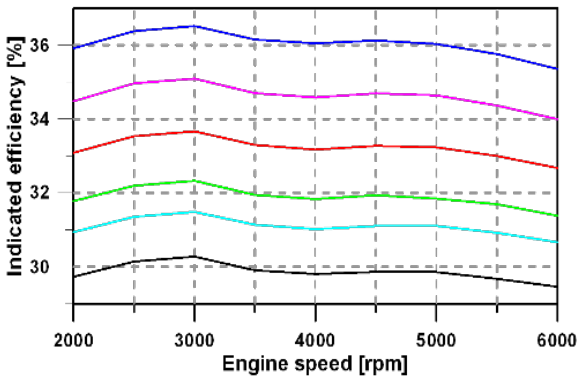


Fig. 8. Effect of biogas on indicated efficiency of range extender engine.

3.3. Engine emissions characteristics

Figure 9 shows higher NOx emissions corresponded with a decrease in biogas content in the fuel. High octane gasoline has higher hydrocarbons characteristic than biogas which mostly contains methane, therefore increased the flame speed, furthermore, increasing the combustion temperatures and finally producing more NOx emissions. The NOx emission for pure gasoline was higher than pure biogas, this is due to the fact that the engine was designed and calibrated for gasoline, resulted high temperature combustion which produces more NOx. As biogas has a lower flame speed than gasoline due to which the combustion occurs at the end of power stroke and continues for a longer time in expansion stroke. Therefore, slower combustion is happened, resulted lower peak and consequently the combustion temperature is also decrease [21]. The other reason is that biogas has smaller mass density compared to gasoline, which promotes the lean mixing combustion. Furthermore, due to biogas was fumigated at intake port; the oxygen charged to the engine is decreased. The lean mixing combustion with small amount oxygen leads to the slower burning duration and lower temperature combustion [20]. Finally, the NOx emission will be lower.

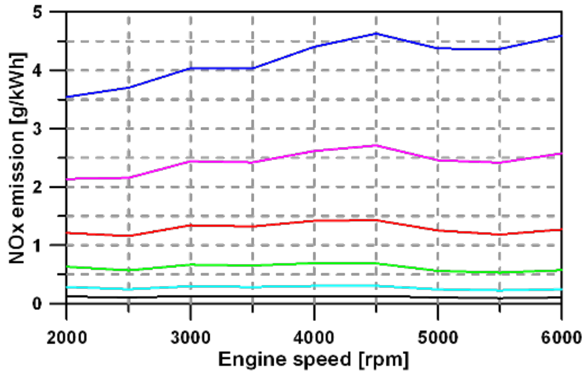


Fig. 9. Effect of biogas on NOx emission of range extender engine.

Figure 10 shows the effect of biogas on CO emission of range extender engine. CO is a harmful gas but colourless and odourless, which is mainly produced when engine is run with rich fuel equivalent ratio. When there is lack of oxygen to combust all carbon-to-carbon dioxide, a partially fuel uncompleted burned and some carbon eventually becomes CO. Biogas mainly contains methane, which has low hydrocarbon ratio and small carbon aggregate in its structure [22]. Methane has small content of carbon. Due to the small carbon structure, the combustion results of biogas that is CO emission should be lower than gasoline. However, in this study the increase biogas content, the CO emission was also increase. This condition can be explained due to the engine designed and structured for gasoline fuel. Therefore, when using biogas fuel, some amount of biogas was not completely burned. The higher in emission of CO is because of unstable combustion such as misfiring and knocking which includes incomplete oxidation that generates CO [21]. Thus, the emission of CO becomes higher. To overcome this situation some strategy such as changing compression ration or managing the start of combustion and combustion duration by adjusting spark timing can be adopted in this study.

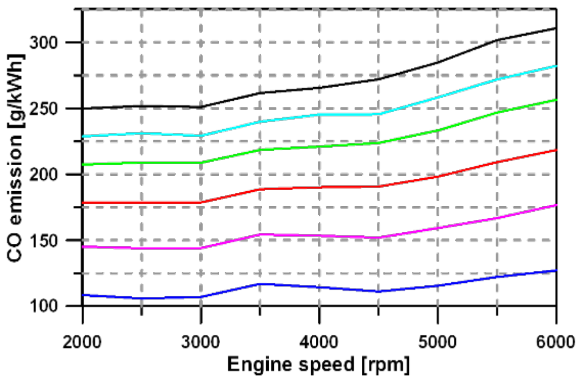


Fig. 10. Effect of biogas on CO emission of range extender engine.

Hydrocarbon is one of the harmful emissions which cause lung and blood diseases. Figure 11 depicts the effect of biogas on HC emission or range extender engine. The increasing of biogas content in the fuel leads to the increasing of HC emission. As already known that biogas main component is methane in a high concentration. Previous study [22] explained that methane has some characteristics including the high quenching distances and zones, furthermore it is also having volatile hydrocarbon structure. Therefore, HC emission is increase when biogas was used to substitute fuel for gasoline as represented in this study. It was also suggested that for optimal utilization of biogas, crevice zones, electrode gaps, valve seats, piston ring gaps and sealing gaps in the engine should be adjusted optimally [22]. The inappropriate design of the spark ignition engine originated for gasoline fuel but fuelled with biogas can be another reason of the higher hydrocarbon emission.

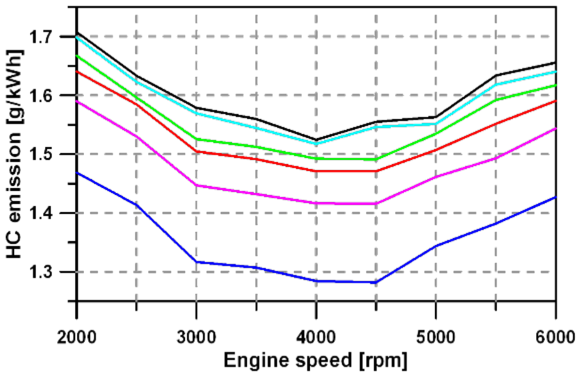


Fig. 11. Effect of biogas on HC emission of range extender engine.

Many mechanisms can produce hydrocarbon in SI engine; however the main cause is through the increase of dilution incomplete combustion. The increasing of dilution, unburned gas temperature and pressure during combustion is lower, produce the lower combustion characteristics. Normally, some amounts of the unburned hydrocarbons that discharge from the main combustion process are oxidized during the next step of the expansion stroke, and during the exhaust cycle. However, with expanding dilution, exhaust temperatures are decrease, resulting in poor oxidation and make worse of the condition where already almost huge hydrocarbon emissions have developed from unfinished combustion [22].

4. Conclusion

Simulation study on the performance and exhaust emissions behaviours of range extender spark ignition engine fuelled with biogas applied for small electric vehicles have been carried out. The simulation result was validated by using experimental data from the reference which no significant different was obtained. Performance parameters of the range extender SI engine including IMEP, Power, and indicated efficiency are decrease following the higher content of biogas in the fuel. Meanwhile, the NO_x emission of range extender SI engine showed a better improvement when using biogas. However, the emissions of HC and CO were increase by the increasing of biogas percentage in the fuel. It can be concluded that even though the performance of range extender SI engine decreased when using biogas, but it can be used to fulfil small electric vehicle needs which the requirement of charging power is at least 20 kW.

Author Contributions

Y.P., H.E.P, A.P., and W.B.S. have been contributed equally as the main contributor. Y.P. carried out the development of the concept of the paper, performed the literature study, prepared the paper structure, aim, objectives, research question, analysed the data, and as well as writing the paper. H.E.P supervised the simulation and mathematics calculation. A.P. created the simulation and modelling. W.B.S supervised the research, advised on the research gap and objective, proofread the paper, and guided the writing process as well as reviewing the presented concepts and outcomes. A.D., M.P., S., and A.N., support the design and experimental work of RE engine. All authors read and approved the final paper.

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Nomenclatures

b and u	Burned and unburned zone
C	Cylinder
CL	Air Cleaner
c_m	Average speed of piston
c_u	Circumferential velocity
D	Cylinder diameter
E	Engine
I	Injector
MP	Measuring Point
$p_{c,0}$	Motoring cylinder pressure
$p_{c,1}$	Pressure in the chamber at IVC
PL	Plenum
R	Restriction
SB	System Boundary
$T_{c,1}$	Temperature in the chamber at intake valve closing (IVC)
V_D	Swept volume of engine
W_{air}	Air mass fraction
W_{CP}	Combustion products mass fraction
W_{FV}	Fuel vapour mass fraction

Abbreviations

CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon dioxide
EVs	Electric Vehicles
GUI	Graphical User Interface
H_2S	Hydrogen Sulphide
HC	Hydrocarbon
HEVs	Hybrid Electric Vehicles

ICE	Internal Combustion Engine
IFSC	Indicated Fuel Specific Consumption
IMEP	Indicated Mean Effective Pressure
kW	kilo Watt
LIPI	Lembaga Ilmu Pengetahuan Indonesia (Indonesian Institute of Sciences)
LPG	Liquid Petroleum Gas
MGT	Micro Gas Turbine
N_2	Nitrogen
NHV	Noise, Vibration and Harshness
NOx	Nitrogen Oxide
REEV	Range-Extended Electric Vehicle
SI	Spark Ignition

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