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A Study on Designing of an Electronically Operated Fuel Supply System for a Simulated Biogas SI Single Cylinder Engine

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Abstract: This paper presents the development of an electronically operated fuel supply system (EOSS) for a spark ignition engine using simulated biogas. Simulated biogas is formed by the mixing of methane gas (CH_4) and carbon dioxide (CO_2) under different mixing ratio between 50/50 and 80/20 in percentage. The simulated biogas is supplied to intake manifold of a high compression ratio diesel DI engine that converted to use gas fuels for high efficiency purpose. EOSS is studied to control CH_4/CO_2 ratio and air fuel ratio of simulated biogas engine. The obtained results show the principle of CH_4/CO_2 control and the ratio control of the air mass flow and fuel mass flow. The preliminary testing activities are also performed to understand the relation between operating parameters and the key parameters of EOSS.

Keywords: *High Compression Ratio SI Engines, Simulated Biogas, Biogas Mixture, Biogas Enrichment with Methane.*

Introduction:

The world is faced with crises of fossil fuel shortage and environment degradation as a direct result of growth in population, urbanization and industrialization. World's main energy resources will be depleted within the several decades. Thus, the study on alternative fuel engine is becoming an important research topic nowadays [1, 2].

Biogas is a great choice among many alternative fuels, especially in the countryside. The idea of using biogas in an engine converted from diesel (DI) engine is not new, but it is still an attractive alternative fuel. In a research of Henham about simulated biogas in a dual-fuel diesel engine, the normal diesel fuel injection system still supplies a certain amount of diesel fuel. The mixing device was designed to make the air – gas mixture. The design calculations to evaluate diameter of the pipe for gas inlet are based on the parameters - rated power, cubic capacity, rated speed, volumetric efficiency, manifold diameter, diesel substitution, gas caloric value and velocity of gas [3]. Another research in biogas – gasoline engine was established an air–fuel ratio control model. According to the open degree of air valve, a micro control unit (MCU) was used to control the expansion amount of stepper motor which can determine the supply amount of biogas directly. For the best air–fuel ratio of the mixture, the expansion amount of stepper motor h can be controlled by the air valve opening angle θ.

The mass flow rate of air and gas was calculated, the air velocity and the biogas velocity can be acquired based on the Bernoulli equation [4].

An air–fuel ratio control system in gaseous automotive engine which combines with open loop control and closed loop control. Mixture supply is controlled by the curve of engine speed and regulating valve which is calculated and managed by electronic MCU unit [5]. The supply system using carburettor to mixing air and biogas together. Biogas was supplied into the intake manifold at appropriate quantity. For manifold supply of biogas, a solenoid operated valve was used. It was operated with 12V DC power supply [6]. In electronic fuel supply system, a flat-type air consumption measuring device is used whereas the position of the flat is proportional to the amount of air. In fact, a flat-type air consumption measuring device inhibits the influx of air into the engine. This research also present the air consumption measuring devices with a heating element [7].

From previous publications, biogas composed of various gases such as CH_4 (50 – 70%), CO_2 (30 – 50%), N_2 (<1%) and H_2S (10 – 2000 ppm) [1,3]. This study design an electronically operated fuel supply system (EOS) which supplying simulated biogas with CH_4 – CO_2 under different mixing ratio between 50-50 and 80-20 in percentage. The simulated biogas supply by injector under engine speed.

Materials and Methods:

In this research, basic technical characteristics of the engine are shown in Table1.

Table 1. Parameters of converted engine

Parameter	Value
Displacement (cm^3)	709
Number of cylinders	1
Compression ratio	18
Power (kW/rpm)	10.3/2400
Torque (N.m/rpm)	49/1600
Bore (mm)	97
Stroke (mm)	96

The working principle of simulated biogas supply system is shown in fig 1. The Injector 1 supply CH_4 gas and the Injector 2 supply CO_2 gas. These Injectors are controlled by ECU1. The Injector 3 supplies the simulated biogas and controlled by ECU2. A Throttle valve device inhibits the influx of air into the engine.

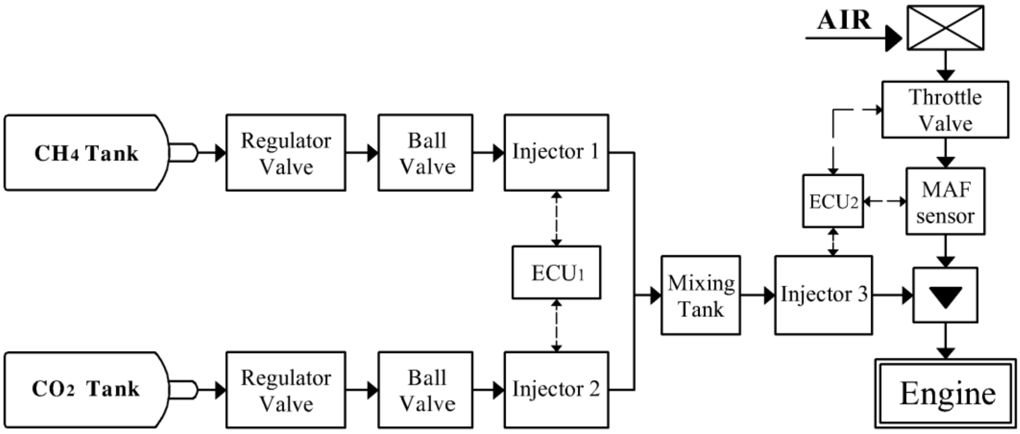

Figure 1: Simulated biogas supply system

Figure 2: The injector using in the system (BF-300 CNG/LPG injector)

The air – fuel ratio stoichiometric in the mixing of CH_4 and CO_2 under different ratio between 50-50 and 80-20 calculated from biogas combustion equation (1) and the value is presented in Table 2.

$$aCH_4 + bCO_2 + 2a(O_2 + 3.76N_2) \rightarrow (a + b)\, CO_2 + 2a\, H_2O + 2a\,(3.76N_2) \quad (1)$$

The air – fuel ratio stoichiometric can be acquired by:

$$\left(\frac{A}{F}\right)_{stoi} = \frac{\dot{m}_{air}}{\dot{m}_{fuel}} = \frac{2a.\left(M_{O_2} + 3{,}76 M_{N_2}\right)}{a.M_{CH_4} + b.M_{CO_2}} \quad (2)$$

Table 2. Air – fuel ratio Stoichiometric

CH_4 – CO_2 ratio	Value
80 – 20	10.2
75 – 25	9
70 – 30	7.87
65 – 35	6.9
60 – 40	6.09
55 – 45	5.3
50 – 50	4.6

Calculated the supplying of the Injector 1 and Injector 2.

The mass of air – fuel supply to cylinder at exactly revolution in one second can acquire by equation (3):

$$m_{a-f} = \frac{V_h.n.\rho}{120} \quad \text{(kg/s)} \quad (3)$$

Where,

V_h: Volume of cylinder (m^3);

n: Revolution of crankshaft (rpm);

ρ: Density of air at 30°C (kg/m^3);

m_a: Mass of air;

m_f: Mass of simulated biogas

The relative air/fuel ratio λ =1. The mass of air and the mass of fuel are determined by equations (4):

$$\begin{cases} m_{a-f} = m_a + m_f \\ \left.\dfrac{m_a}{m_f}\right._{real} = \left.\dfrac{m_A}{m_F}\right._{stoi} \end{cases} \quad (4)$$

Density of simulated biogas is determined by equation (1.5):

$$\rho_f = \left(\frac{\rho_{CH_4}.\%CH_4}{100} + \frac{\rho_{CO_2}.\%CO_2}{100}\right).p_{gas} \quad (5)$$

Where,

ρ_f: Density of simulated biogas (follow the ratio) (kg/m^3)

ρ_{CH_4} : Density of CH_4 (kg/m^3)

ρ_{CO_2} : Density of CO_2 (kg/m^3)

p_{gas} : Pressure in the supplying tube (bar)

Table 3. Density of Simulated biogas (*p_{gas} = 3 bar)*

$CH_4 - CO_2$ ratio	Density ρ (kg/m3)
80/20	2.708
75/25	2.885
70/30	3.061
65/35	3.237
60/40	3.413
55/45	3.589
50/50	3.765

The volume of supply simulated biogas is calculi-ted by equations:

$$V_{CH_4} = \frac{m_f}{\rho_f} \cdot \frac{\%CH_4}{100} \quad (\text{m}^3/\text{s}) \quad (6)$$

$$V_{CO_2} = \frac{m_f}{\rho_f} \cdot \frac{\%CO_2}{100} \quad (\text{m}^3/\text{s}) \quad (7)$$

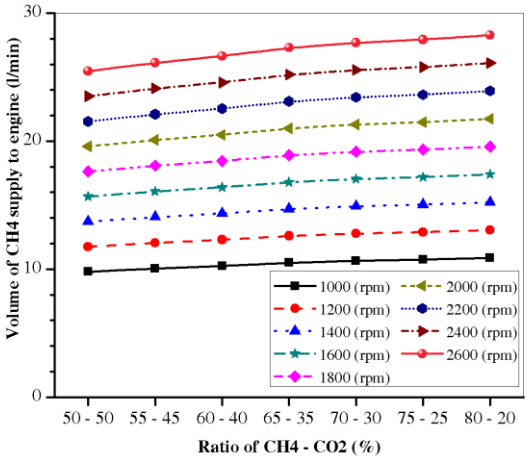

Figure 3: Volume of CH_4 supplying to engine

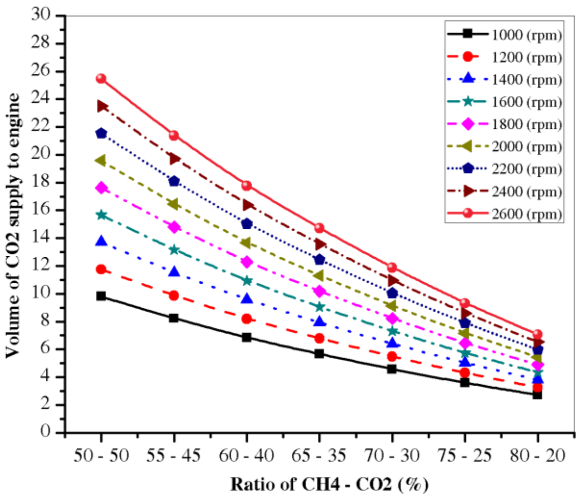

Figure 4: Volume of CO_2 supplying to engine

The opening time of the injector hole can be acquired by equation (8):

$$t_{CH_4,CO_2} = \frac{V_{CH_4,CO_2}}{V_{hole}} \quad (\text{s}) \quad (8)$$

Where,

V_{hole} : The mass flow rate of the injector hole = 0.0027 m^3/s

Calculated supplying of the injector 3.

The Injector 3 working depends on the actual air going into the engine. And the air is also measured by the MAF sensor (Mass air flow sensor–air consumption measuring devices with a heating element). Fig. 5 depicts the relation between the voltage of the MAF sensor and the air mass. The voltage is used as the output signals of the sensor.

With the relative air/fuel ratio λ =1. The mass of supplying simulated biogas depend on the mass of air (the MAF sensor measured) and the opening time of the injector 3 can be determined by equations:

$$\dot{m}_f = \frac{\dot{m}_a}{A/F_{Stoi}.3600} \quad (9)$$

$$Q_1 = \frac{\dot{m}_f}{\rho_f} \quad (10)$$

$$t_{\text{inj3}} = \frac{Q_1}{0.0027} \quad (11)$$

Where,

$\dot{m}_f$: The mass of simulated biogas calculated from the mass of actual air (kg/s)

Q_1 : The volume flow rate of simulated biogas (m^3/s)

t_{inj3} : The opening time of the injector 3 (s)

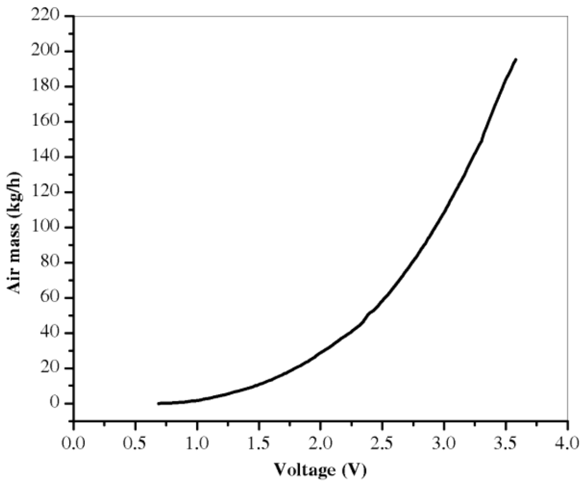

Figure 5: The relation between the voltage of MAF sensor and the air mass

Design of Electronic Control Unit (ECU):

In this research, the ARM Cortex STM32F4 microcontroller is utilized as the controller in ECU. The fuel and air flow rates that go through injectors is controlled by PWM technique. ECU work real-time and it supply exactly the amount of fuel which is demand of the engine. Based on above simulation results, the look up table for engine speed and biogas ratio/volume is established in the MCU. From look up table, the PWM pulse width is calculated and sent to injectors. Figure 6 shows the ECU using STM32F4 discovery board.

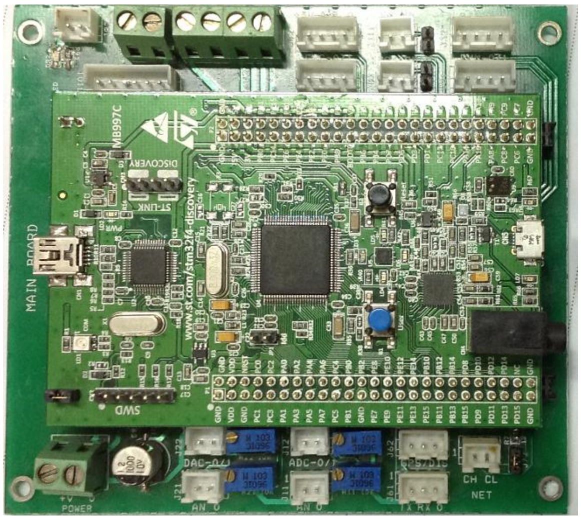

Figure 6: ECU Board

To drive the ejectors, the amplifier circuit (as shown in Figure 7) is employed to increase current from PWM signals.

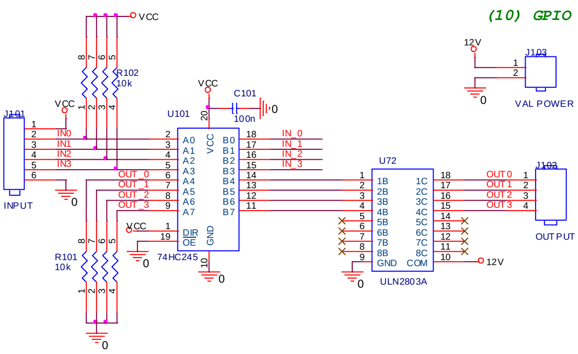

Figure 7: Ejector driving circuit

Conclusion:

In this paper, the research on simulated biogas was investigated. The relationship between biogas ratio/volume and engine speed is study. Besides, the electronic control unit is designed to control the biogas flow rate and volume. This ECU system works like another system in automotive. It supplies exactly the amount of fuel which is demand of the engine immediately.

In the future, this system is still developed to get more exactly and cheaper.

Acknowledgement

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References:

[1] Ertugrul D. O., (2013) "Biogas Production from Household Wastes: A Quantitative Feasibility Study for Student Apartments in Albano", MJ153x Bachelor's Thesis for Energy and Environment, Stockholm 2013.

[2] NSCA, (2006) "*Biogas as a road transport fuel",* The National Society for Clean Air and Environmental Protection, ISBN 0-903-47461-1, England, June 2006.

[3] Henham A., (1998) "Combustion of Simulated biogas in a dual-fuel diesel engine", Energy Conversion and Management Vol.39, pp.2001-2009, United Kingdom.

[4] Su Chu. W., Ye Shu J., "The design and Study on the mixture control system of the biogas-gasoline dual-fuel engine", IEEE 2011, ISBN 978-1-61284-749-8.

[5] Hongwei C., "Experimental Study on Air Fuel ratio control in Gaseous Automotive engine", IEEE 2010, ISBN 978-1-4244-5537-9.

[6] Prashant S. D., Yadav S. D., (2013) "Electronically operated fuel supply system to control air fuel ratio of biogas engine" IEEE 2013, ISBN 978-1-4673-6149-1.

[7] Ilves R., Olt J., "Study of prior art of spark ignition engine fuel supply system", Agronomy Research Biosystem Engineering special Issue 1, 55-74, 2012.