VARIATION IN LOAD AND SPEED TOWARDS EXHAUST GAS EMISSION OF GAS ENGINE JGS 208 GS

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ABSTRACT

This research conducted to study the effect of speed and load variation on the flue gas emissions from a gas engine JGS 208 GS fueled with LPG. Load variation conducted is at 20, 40, 60, 80 and 100 (kW) while the variation of speed is at 1100, 1300, 1500 and 1700 rpm. The results of this research show the increase of load tends to decrease the exhaust gas emissions of CO, HC but on the contrary for the exhaust gas emission of NOx. This research also show that the increase of engine rotation tends to increase the exhaust gas emissions of CO, HC and NOx at the fifth load variations. The lowest exhaust gas emissions of CO and HC were found at the speed, n of 1100 rpm and the load, P of 100 kW while the highest exhaust gas emissions of CO and HC were found at the speed, n of 1700 rpm and the load, P of 20 kW.

Keywords: load variation, speed, emission, gas engine

Introduction

The increasing price of world crude oil nowadays results in the government of Indonesia should bear a very heavy burden to give subsidy to the society, the users of that fuel. The amount of subsidy given is in directly proporsion to the increase of crude oil prices. One of the solutions to reduce the burden on subsidy is by increasing the selling price of the products of oil refinery in accordance with the increase of world oil price. Nevertheless, this solution is not popular to the society generally and to the poor people in particular.

Nowadays, another solution conducted by the government in order to reduce the burden of subsidy is to convert the use of oil fuel (kerosene, gasoline and diesel oils) to liquefied petroleum gas (LPG) having lower price and friendlier environment.

The idea of this research is to help the government for introducing the use of gas fuel having friendly environment and also to reduce the use of oil fuel in which its reserve is running low and limited and also its price is getting higher and higher.

Combustion processes in an internal combustion engine result in flue gas emissions categorized in six different elements [4], i.e.:

1). Carbon monoxide (CO)
2). Hydrocarbon (HC)
3). Oxides of nitrogen (NOx)
4). Oxides of sulphur (SOx)
5). Particulate matter 10 microns or smaller (PM_{10})
6). Aldehydes (CHO)

The composition of the flue gas emissions really depends on the fuel composition, tipically consisting of 73,9% N_2; 10,4% H_2O; 9,4% O_2; 5,2% CO_2; 0,8% Ar; 0,24% THC; 0,045% CO dan 0,015% NOx [4]. The composition of LPG used in this research is 50% butane dan 50% pentane therefore its flue gas emission consists of CO, HC dan NOx, mainly.

One of influencing factors in the formation of CO emission is the availability of oxygen or air in a fuel combustion process. When the combustion process is going on the lack of air ($\lambda < 1$), the formation of CO will be more intensive due to the lack of oxygen to convert CO to be CO_2. Otherwise, when the combustion process is going on excess air ($\lambda > 1$), the formation of CO will be less intensive due to the availability of oxygen to oxidise further CO to be CO_2 [2].

Spark ignition engines, generally, are operated around stoichiometry at part loads and on fuel rich mixture at full loads therefore CO emission is quite high and should be controlled [1]. The exhaust gas of CO emitted by an automobile is a poisonous gas and is known to cause nausea, fatique and at high concentration it can cause death [3].

Liquefied Petroleum Gas (LPG) is a fuel consisting of hydrocarbon gases such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}) and other long-chain compounds. A small fraction of these hydrocarbons will pass the combustion chamber without any reaction therefore it will exist in the exhaust gas. Suatu fraksi yang kecil dari hidrokarbon-hidrokarbon ini akan melewati ruang bakar tanpa bereaksi sehingga akan ditemukan dalam gas buang. Hydrocarbon emissions, generally, can be divided into three categories, i.e., 1). Total Hydrocarbons (THC) or Total Organic Compounds (TOC)**,** 2). Non-Methane Hydrocarbons (NMHC) or Volatile Organic Compounds (VOC) or Reactive Organic Compouns (ROC), and 3). Non-Methane Non-Ethane Hydrocarbons (NMHC-NEHC).

THC emissions are all hydrocarbon gases existing in the exhaust gas stream. NMHC emissions are all THC compounds except methane gas. In addition, NMHC emissions can react with NOx at lower layer of atmosphere and act as a precursor to form photochemical smog. Methane emission will not react directly with smog at the lower layer of atmosphere. Ethane emission can be neglected at some controlled areas because the gas has a lower activity compared with long-chain hydrocarbons. In this area, the regulation is based on NMHC-NEHC.

Basically, nitrogen oxides (NOx) consist of nitric oxide molecules (NO) and nitrogen dioxide (NO_2) formed if nitrogen (N_2) and oxygen (O_2) from air react each other. This reaction need a high combustion temperature and the presence of nitrogen and oxygen in combustion chamber after the fuel has burnt.

Elements of nitrogen dioxide (NO_2) are dangerous to people and animals causing the decrease of breathing capacity and blood capability to bring O_2. Emision of NO_2 is also dangerous to plants. At lower atmosphere, when exposed to sun light, NO_2 and NO act as precursor in the form of O_3 (ozone). Ozone, at lower atmosphere, can destroy plants and synthetic materials and also can result in a cough and headache for people. Photochemical smog consists of yellowish NO_2 and ozone [5].

In cylinder, NO is produced dominantly compared with NO_2 whereas NOx is oxidation product of nitrogen compound containing in its fuel and combustion air. Exhaust gases of NO dan NO_2, generally, react further if the temperature in the combustion chamber above 1800 C with the reaction as follows [6]:

$$\left.\begin{aligned} O + N_2 &\longrightarrow NO + N \\ N + O_2 &\longrightarrow NO + O \\ N + OH &\longrightarrow NO + H \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The amount of NO gas resulting from the above reactions depends on residence time of reaction inside the cylinder and environment temperature. The three above reactions are chemical reaction to form NO called Zeldovich's developed mechanism (for the first two reactions) and added by Lavoie (for the last reaction).

When the composition of a fuel is known, theoretical air-fuel ratio (stoichiometry) can be determined. For hydrocarbon fuel, general form of its combustion chemical equation with air is shown below:

$$C_nH_m + (1 + e)(n + m/4)(O_2 + 3{,}76\,N_2) \longrightarrow$$
$$n\,CO_2 + (m/2)\,H_2O + e\,(n + m/4)\,O_2 +$$
$$3{,}76\,(n + m/4)(1 + e)\,N_2 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where:
n = the amount of atoms of carbon elements
m = the amount of atoms of hydrogen elements
e = the fraction of excess air

Lambda (λ) or Air Ratio can be defined as a ratio between air mass supplied and air mass required for stoichiometric combustion or a ratio between air-fuel ratio supplied and air-fuel ratio required for stoichiometric combustion, written as:

$$\lambda = \frac{\dot{m}_{air}}{\dot{m}_{st.\,air}} = \frac{(A/F)_{act.}}{(A/F)_{st.}} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where:
$\dot{m}_{air}$ = air mass supplied
$\dot{m}_{st.air}$ = air mass required for stoichiometric combustion
$(A/F)_{act.}$ = air-fuel ratio supplied (actual)
$(A/F)_{st.}$ = air-fuel ratio requied for stoichiometric combustion

Air ratio is a good influence on characterising a combustion process and can be determined by measuring air and fuel mass flow rates supplied in

ISBN: 978-602-97742-0-7

combustion process. When air ratio is less than one, the air-fuel mixture is called a rich mixture, but when air ratio is more than one, the air-fuel mixture is called a lean mixture. In addition, when air ratio is equal to one, the air-fuel mixture is called a perfect mixture or stoichiometry [1].

Combustion product highly depends on air ratio occurred. Composition of combustion product is different between lean and rich and mixtures and also stoichiometry. Theoretically, when the mixture is leaner, the efficiency of the engine becomes higher and exhaust gas emission is getting friendlier to the environment. Nevertheless, in a practical way, an engine will reach an operational point richer than a predicted one due to the failure of perfect combustion and also due to unstability of combustion start. Akan tetapi, dalam prakteknya, suatu mesin akan mencapai suatu titik operasi yang lebih kaya dari yang diprediksi sebagai akibat kegagalan pembakaran dengan sempurna dan juga akibat awal pembakaran yang tidak stabil. When air-fuel ratio is getting higher, usually, the velocity of the flame is decreasing and the mixture is difficult to be ignited [3].

2. Experiment

2.1 "Gas Engine" Instalation

"Gas Engine" used in this research is an LPG fueled engine (JGS 208 GS type) and operated to produce optimal electrical power of 175 kW. This engine has 8 cylinders , horizontal position, 4 stroke and equipped with lubrication, fuel, exhaust gas and control systems. The arrangement of the gas engine can be seen in Figure 1.

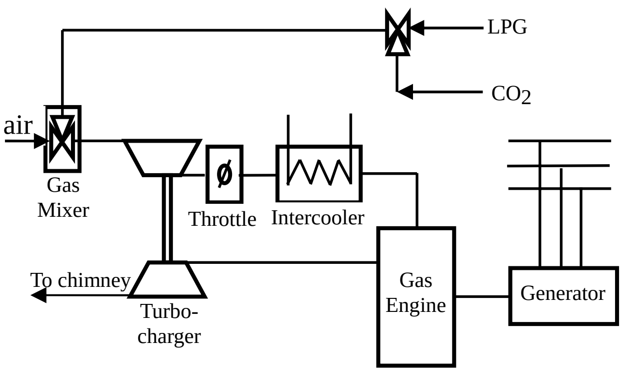

Figure 1. Layout of JGS 208 GS gas engine equipped with turbocharger and intercooler and also fuelled with LPG

Before operating the gas engine, "jacket water" temperature will be increased to 42 C. The engine is equipped with a gas mixer functioning as a mixer between LPG and air in accordance with the ratio needed. The gas and air mixture is then sucked by a compressor installed in a turbocharger, and moreover, the mixture will be passed through a throttle valve to regulate mass flow rate of the mixture in accordance with the load occurred. After passing the throttle valve, the mixture will be passed through an intercooler before entering each cylinder based on the its order.

The combustion process in each cylinder will occure in accordance with firing order. Combustion product gas will leave the cylinders through exit valves and before entering the atmosphere, the gas will be passed through a turbocharger to drive a turbine inside it. The gas engine cycle is four strokes, i.e., suction/intake stroke, compression stroke, expansion/power stroke and exhaust stroke. In a cycle, an engine needs two crank shaft rotations or four piston strokes.

3. Results and Discussion

This research was conducted by fuelling with LPG consisting of 50 % propane (C_3H_8) and the load (P) was varied at 20, 40, 60, 80 dan 100 kW while the velocity of the crank shaft (n) was varied at 1100, 1300, 1500 dan 1700 rpm. Exhaust gas emissions of CO, HC and NOx (ppm) were measured at each condition varied and the results can be seen in Table 1 below.

Table 1. Data collected from the Gas Engine fuelled with LPG

Load (kW)	Rotation, n = 1100 rpm			Rotation, n = 1300 rpm		
	CO*	HC*	NOx*	CO*	HC*	NOx*
20	1877	230	30	1890	370	34
40	1750	145	44	1778	265	55
60	1556	120	77	1618	140	90
80	1364	97	97	1530	120	122
100	1148	93	142	1350	105	150
Load (kW)	**Rotation, n = 1500 rpm**			**Rotation, n = 1700 rpm**		
	CO*	HC*	NOx*	CO*	HC*	NOx*
20	1992	423	47	2295	740	52
40	1884	296	76	2114	520	98
60	1754	237	107	1960	340	134
80	1631	124	131	1840	253	165
100	1497	120	161	1750	205	176

Note: * dalam ppm

ISBN: 978-602-97742-0-7

3.1 Analysis of the Effect of Load (P) and Rotation (n) towards Exhaust Gas Emission of CO

Exhaust gas emission is a gas of combustion product of LPG (fuel) and air in a cylinder. Data of varied load (P) and rotation (n) towards exhaust gas emission of CO (ppm) can be seen in Table 2 below.

Table 2. Exhaust gas emission of CO (ppm) at varied load, P (kW)

No.	Load, P (kW)	Exhaust Gas Emission of CO (ppm)			
		n = 1100 rpm	n = 1300 rpm	n = 1500 rpm	n = 1700 rpm
1.	20	1877	1890	1992	2295
2.	40	1750	1778	1884	2114
3.	60	1556	1618	1754	1960
4.	80	1364	1530	1631	1840
5.	100	1148	1350	1497	1750

The above data shows that the increase of load will result in decreasing of exhaust gas emission of CO at the fourth rotations operated. In addition, the increase of rotation will result in increasing of exhaust gas emission of CO at the fifth varied loads conducted. The graph of influencing loads, P (kW) and rotations, n (rpm) towards exhaust gas emission of CO can be seen at Figure 2 below.

The most influencing factor in forming the exhaust gas emission of CO inside the engine cylinder is the ratio of air-fuel mixture. If oxygen (O_2) is available enough in combustion chamber, the element of carbon in combuston chamber will burn perfectly to form carbon dioxide (CO_2) but if oxygen is not available enough, the combustion is not complete therefore the element of carbon will react with oxygen to form carbon monoxide (CO). Due to that reason, the combustion with less oxygen or rich mixture will result in exhaust gas emission of CO in a certain amount but the combustion with more oxygen or lean mixture will result in mostly exhaust gas emission of carbon dioxide (CO_2).

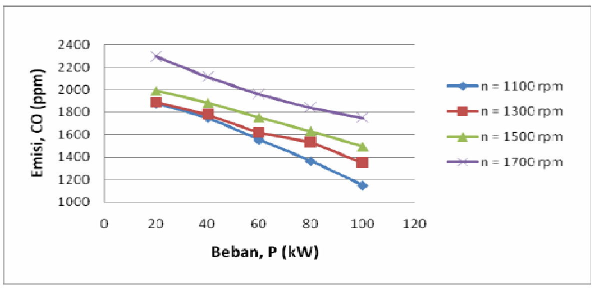

Figure 2. The effect of varied load, P (kW) and speed, n (rpm) towards exhaust gas emission of CO (ppm)

3.2 Analysis of the Effect of Load (P) and Rotation (n) towards Exhaust Gas Emission of HC

Exhaust gas emission of HC is an element of unburned hydrocarbon due to incomplete combustion in the combustion chamber. The increase of exhaust gas emission of HC will result in the increase of fuel consumption and also the decrease of engine power produced. Several factors affecting the high exhaust gas emission of HC are the failure of ignition apparatus (coil, distributor, spark plug cable), inaccuracy of spark plug electrode gap, too early ignition time, and also mechanical problems such as the wearing on piston ring, and wrong setting of valves.

Data of varied load (P) and speed (n) towards exhaust gas emission of HC (ppm) can be seen in Table 3 below.

Table 3. Exhaust gas emission of HC (ppm) at varied load, P (kW)

No.	Load, P (kW)	Exhaust Gas Emission of HC (ppm)			
		n = 1100 rpm	n = 1300 rpm	n = 1500 rpm	n = 1700 rpm
1.	20	230	370	423	740
2.	40	145	265	296	520
3.	60	120	140	237	340
4.	80	97	120	124	253
5.	100	93	105	120	205

The above results show that the increase of load will decrease the exhaust gas emission of HC at fourth speeds operated. In addition, the increase of speed will also result in increasing of exhaust gas emission of HC at the fifth varied loads conducted. The effect of load, P (kW) and rotation, n (rpm) towards the exhaust gas emission of HC can be seen in Figure 3 below.

ISBN: 978-602-97742-0-7

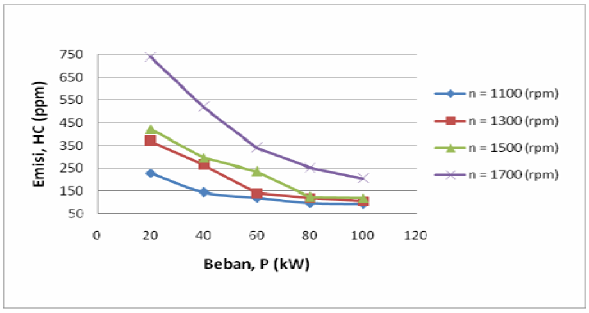

Figure 3. The effect of varied load, P (kW) and rotation, n (rpm) towards exhaust gas emission of HC (ppm)

3.3 Analysis of the Effect of Load (P) and Rotation (n) towards Exhaust Gas Emission of NOx

Data of varied load (P) and speed (n) towards exhaust gas emission of NOx (ppm) can be seen in Table 4 below.

Table 4. Exhaust gas emission of NOx (ppm) at varied load, P (kW)

No.	Load, P (kW)	Exhaust Gas Emission of NOx (ppm)			
		n = 1100 rpm	n = 1300 rpm	n = 1500 rpm	n = 1700 rpm
1.	20	30	34	47	52
2.	40	44	55	76	98
3.	60	77	90	107	134
4.	80	97	122	131	165
5.	100	142	150	161	176

The above data shows that the increase of load will result in increasing of exhaust gas emission of NOx at the fourth rotations operated. In addition, the increase of rotation will result in increasing of exhaust gas emission of NOx at the fifth varied loads conducted. The graph of influencing loads, P (kW) and rotations, n (rpm) towards exhaust gas emission of NOx can be seen at Figure 4 below.

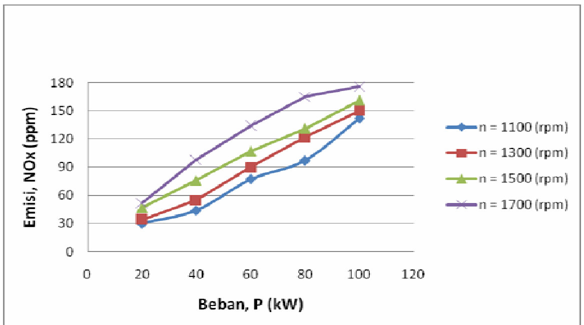

Figure 4. The effect of varied load, P (kW) and speed, n (rpm) towards exhaust gas emission of NOx (ppm)

4. Conclusion

From this research it can be concluded as follows:

1. The increase of load, P (kW) and the decrease of rotation, n (rpm) will result in decreasing the exhaust gas emission of CO. The minimum exhaust gas emission of CO of 1148 ppm was obtained at the maximum load, P_{max} of 100 kW and the minimum speed, n_{min} of 1100 (rpm). But the maximum exhaust gas emission of CO of 2295 ppm was obtained at the minimum load, P_{min} of 20 kW and the maximum speed, n_{max} of 1700 (rpm).
2. The increase of load, P (kW) and the decrease of rotation, n (rpm) will result in decreasing the exhaust gas emission of HC. The minimum exhaust gas emission of HC of 93 ppm was obtained at the maximum load, P_{max} of 100 kW and the minimum speed, n_{min} of 1100 (rpm). But the maximum exhaust gas emission of HC of 740 ppm was obtained at the minimum load, P_{min} of 20 kW and the maximum speed, n_{max} of 1700 (rpm).
3. The decrease of load, P (kW) and rotation, n (rpm) will result in decreasing the exhaust gas emission of NOx. The minimum exhaust gas emission of NOx of 30 ppm was obtained at the minimum load, P_{min} of 20 kW and the minimum speed, n_{min} of 1100 (rpm). But the maximum exhaust gas emission of NOx of 176 ppm was obtained at the maximum load, P_{max} of 100 kW and the maximum speed, n_{max} of 1700 (rpm).

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