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GAS QUALITY IMPACT ON GAS ENGINE PERFORMANCE: CASE OF AN INDONESIA NATURAL GAS STATION

Rizki Wijanarto Budiman[1], Riman Sipahutar[2]

[1]*Department of Mechanical Engineering, Universitas Sriwijaya, Palembang, South Sumatera, Indonesia*
[2]*Department of Mechanical Engineering, Universitas Sriwijaya, Palembang, South Sumatera, Indonesia*
[1] *rizki.w.budiman@gmail.com* [2] *rimansipahutar@ft.unsri.ac.id*

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ABSTRACT

This research was conducted to find a correlation between changes in the variable composition of the natural gas fuel in gas engine generators, and the occurrence of a unit shutdown at a natural gas distribution facility in South Sumatra-Indonesia. The analysis is carried out by investigating the trend of changes in gas composition parameters, and simulation using the Methane Number Calculator application. The results obtained from the research results, in Changes in the composition of fuel gas cause changes in the methane number, Low Heating Value (LHV), High Heating Value (HHV), and Wobbe index (WI), which may indicate engine trouble and cause a unit shutdown. Several options of solutions can be carried out as discussions to solve problems that occur in the gas engine generator at the natural gas distribution facility.

INTRODUCTION

The use of natural gas (NG) in internal combustion engines is an alternative to reduce dependence on oil-based fuels. Natural gas is the most environmentally acceptable fossil fuel, thus it is considered to be an alternative to gasoline and diesel, predominantly used fuels in the transport sector (Al-Enazi et al., 2021; Havrysh et al., 2022). Since natural gas is characterized by a high octane number and high ignition temperature, it is considered as an adequate fuel for engines with spark ignition (Kakaee et al., 2015). The composition of natural gas can vary significantly, depending on the deposits, time of year, and processing methods (Kakaee et al., 2015). Comparing to the composition of commercially available natural gas, some compositions can be characterized with a higher share of higher hydrocarbons, higher share of inert components, etc.

Changes in composition affect physical properties, heating values, as well as behavior during the combustion process (Deymi-Dashtebayaz et al., 2019). This becomes especially important when there are options for using natural gas on exploitation fields, either for combined production of electricity and heat energy in internal combustion engines (Pavlović et al., 2014) or for production of compressed natural gas to be later used in the transport sector. At one of the natural gas station facilities located in South Sumatra, Indonesia, for electricity operational needs, two gas engine generator (GEG) units are installed is work redundancy, and a Diesel Engine Generator (DEG) unit functions as an emergency backup.

The Gas Station has the function of transmitting gas from Gas Producers to consumers, using pipeline transmission. The Gas Station has two transmission pipelines and has been around for more than 15 years of operation. During the 2022 periods, there were four shutdown events that indicated this occurred because of fuel gas quality issue. Figure 1 shows the process block diagram

at the Natural Gas Station facilities. The GEG gets its fuel, from a Gas Producer Plant, which is currently experiencing a change in composition where the CO_2 value has increased, with a range of 5 – 11 vol% during normal operating conditions and can be higher up to 14 vol % when there is maintenance work at the gas producer plant.

NG is a combination of various hydrocarbons. the primary components are usually methane (CH_4; 75−98 vol %), ethane (C_2H_6; 0.5−13 vol %), propane (C_3H_8; 0−2.6 vol %), different more significant hydrocarbons, and inert diluents, including N_2 or CO_2 (Naber et al., 1994). As a result, engine manufacturers are concerned about the gas composition because it can significantly affect engine operation. presently, the most important parameters are used to assess NG first-rate: the methane number (MN) and the Wobbe index (WI) or Wobbe quantity (WN). because the octane scale is not suitable to describe the resistance of NG to knock in ICE applications, an alternative way is to calculate the MN primarily based on the motor octane number (MON) and the reactive H/C ratio. The WI/WN, which describes the electricity content of the gasoline, is the ratio of the fuel heating value in Btu/ft^3 to the square root of its unique gravity with respect to water.

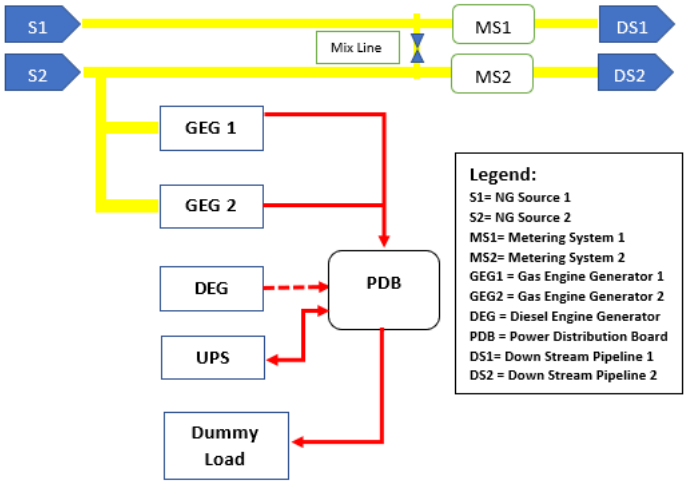


Figure 1. Block Diagram of Natural Gas Station Facilities

During 2022, there were four engine shutdown events, based on this an analysis study was carried out on the effect of gas quality, in this case changes in gas fuel composition on GEG performance. Several studies have been conducted to analyze the effect of gas fuel composition on engine performance. Min et al. (1998) used a 1.5 L gasoline engine converted to NG operation to show that a higher WI can increase engine efficiency up to 20%. Khalil and Karim (2002) used chemical kinetics to show that small changes in the composition of NG, particularly the addition of higher hydrocarbon components (e.g., butane (C_4H_{10}) and heavier, which will drastically reduce the MN), can result in significant changes in the reactivity of fuel.

Hiltner et al. (2003) used a single-zone simulation to demonstrate the effects of NG composition on homogeneous charge compression ignition (HCCI) engines under conditions with a high potential for commercialization. The results showed that the addition of 5−15 vol % higher

hydrocarbons would reduce the required intake manifold temperature and change the residual gas composition. Kim et al. (2009) used a Wiebe function model to investigate NG composition effects in an indirect injection diesel engine modified NG spark-ignition (SI) operation. The results indicated that varying the MN of the fuel from 68 to 100 affected engine performance, fuel economy and burning rate. McTaggart-Cowan et al. (2010) used a heavy-duty NG engine to evaluate the effects of adding ethane and propane to the fuel mix. The results indicated that the addition had no significant effect on the power or fuel consumption of the engine when the MN varied from ~ 80 to ~ 100. Feist et al. (2010) operated five NG engines that operated with gas blends having a MN between 75 and 100. Their study reported only minor effects of MN and WI on engine performance and emissions.

Vavra et al. (2012) used a turbocharged stoichiometric NG SI engine to investigate the effects of adding higher hydrocarbons (C2H6, C3H8, and C4H10 at a maximum of 12, 6, and 3 vol %, respectively) on engine performance. The study found that the changes in the gas composition had minor effects on the knock resistance, power, efficiency, etc. Kakaee et al. (2015) used a dual-fuel NG/diesel computational fluid dynamics (CFD) model to suggest that WN can significantly affect the combustion process. However, the study used just two fuels with a high percentage of inert gas (~20 vol % nitrogen).

Mikulski et al. (2016) which used a similar dual-fuel numerical model to study the gas composition impact when the methane ranged from 10 to 100 vol % (With ethane and propane being the rest), also found that the gas composition had a significant influence on the combustion process. More recently, Amirante et al. (2017) varied the propane fraction from 10 to 40 vol % in a single-cylinder port-fuel-injected SI engine. The experimental results showed that NG composition strongly influenced both engine performance and emissions.

While all of these studies suggested that NG composition is important, in this study an analysis was carried out on the impact of changes in the quality of fuel gas, with various data where CO_2 values were in the range of 5-11% vol, methane in the range79-91%vol, other Hydro carbon up to C6+ , H_2S and H_20 values, on engines that have been operating for more than 15 years with good performance.

METHOD

Data collection was carried out at the location of the Natural Gas Station Facility, South Sumatra, Indonesia. The fuel gas data analyzed is the result of analysis using a metering package system consisting of a gas chromatograph, H_2S analyzer and moisture analyzer. To get LHV, HHV, Wobbe Index and Methane Number values, the Methane Number Calculator application is used. Data was taken over a period of six months (October 2022 – March 2023), and the data selected as sampling data are data that represent significant changes in composition with a CO_2 composition range of 5-11 % Vol. As a comparison data, an analysis is also carried out on changes in the composition of fuel gas every hour for 1 day, where on that date there is a repair of the CO_2 removal facility on the gas producer side, so that the CO_2 composition value is around 10 -11%.

To complete it, data collected for the heating value and CO_2 composition every 2 minute cycle, on one events of engine shutdown in the 2022 period. GEG specifications, shown in Table 1.

Table 1. Specification of Gas Engine Generators

Number of Cylinders	16
Configuration	V Configuration
Rated Speed	1500RPM
Engine net output	926 bkW
Compression Ratio	8:1
Bore x Stroke	170mm x 190mm
Displacement per Cyl.	69000cm ^{3}

Table 2 shows the volumetric composition of four cases of fuel gas with different MN and WI, for basic design of Gas Engine Generator. To get MN, Wi, LHV and HHV values use the Methane Number Calculator application from the Engine Manufacturer.

Table 2. Basic Design Fuel Gas Composition for Gas Engine Generators

Gas Compositions	**Units**	**Basic Design Conditions from Source 2**			
		Case 1	***Case 2***	***Case 3***	***Case 4***
H_2O	% Mole	0.0320	0.0320	0.0320	0.0320
CH_4	% Mole	81.6720	81.6940	82.3290	81.7000
C_2H_6	% Mole	4.9640	4.9650	5.4980	4.9640
C_3H_8	% Mole	3.6550	3.6540	3.9990	3.6540
i-C_4H_{10}	% Mole	0.6970	0.6960	0.7830	0.6960
n-C_4H_{10}	% Mole	0.9420	0.9400	1.0290	0.9400
i-C_5H_{12}	% Mole	0.3290	0.3280	0.4330	0.3270
n-C_5H_{12}	% Mole	0.1600	0.1590	0.1130	0.1590
C_6^+	% Mole	0.1400	0.1240	0.1190	0.1190
N_2	% Mole	2.8200	2.8200	1.2140	2.8210
CO_2	% Mole	4.3240	4.3230	4.0990	4.3230
H_2S	% Mole	0.0000	0.0000	0.0000	0.0000
O_2	% Mole	0.2650	0.2650	0.3520	0.2650
Total	% Mole	100,0000	100,0000	100,0000	100,0000
Methane Number	Btu/Scf	62.9	63.1	62.5	63.2
Wobbe Index	Btu/Scf	1172	1172	1206	1171
HHV	Btu/Scf	1088	1087	1119	1087
LHV	Btu/Scf	984	984	1013	983

From the basic design data we get a number of provisions related to several limitations for gas composition where, the methane number value is in the range 62.5 – 63.2 Btu/Scf, the Wobbe index is in the range 1171 – 1206 Btu/Scf, the HHV is in the range 1087 – 1119 Btu/Scf, and LHV in the range of 983 – 1013 Btu/Scf.

RESULT AND DISCUSSION

Current fuel gas composition from source 2 has a slight difference compare with basic design fuel gas composition, Table 3 shows current fuel gas composition for Gas Engines.

Table 3. Current Fuel Gas Composition from Gas Source 2

Gas Compositions	Units	Current Condition from Source 2			
		Sample 1	***Sample 2***	***Sample 3***	***Sample 4***
H_2O	% Mole	0.0009	0.0009	0.0005	0.0084
CH_4	% Mole	80.4798	81.5756	79.8552	79.2475
C_2H_6	% Mole	6.0024	5.8075	5.7736	5.5700
C_3H_8	% Mole	2.8204	1.2770	1.4332	1.4040
i-C_4H_{10}	% Mole	0.4102	0.2418	0.2693	0.2640
n-C_4H_{10}	% Mole	0.5335	0.3464	0.3834	0.3700
i-C_5H_{12}	% Mole	0.2096	0.1424	0.1512	0.1500
n-C_5H_{12}	% Mole	0.1706	0.1023	0.1064	0.1060
C_6^+	% Mole	0.2545	0.1961	0.2359	0.2401
N_2	% Mole	1.3513	1.3188	1.2151	1.1800
CO_2	% Mole	7.7668	8.9912	10.5762	11.4600
H_2S	% Mole	0.0000	0.0000	0.0000	0.0000
O_2	% Mole	0.0000	0.0000	0.0000	0.0000
Total	% Mole	100,0000	100,0000	100,0000	100,0000
Methane Number	Btu/Scf	64.2	69.6	68.1	68.3
Wobbe Index	Btu/Scf	1122	1076	1052	1035
HHV	Btu/Scf	1051	1000	990	885
LHV	Btu/Scf	951	903	895	979

By making a comparison between the Methane Number and Wobbe Index values at the current fuel gas parameter conditions and the base design, there are only slight differences. In this case the base design has estimated the minimum methane number and is still fulfilled with the current conditions. After getting the methane number value, check the fuel usage guide document from the manufacturer. Table 4. Shows the correlation between derate factor/engine timing and methane number. For example, this engine is designed to deliver its full power rating (say, 1,000 hp) on fuel with a methane number from 83 to 100. When using such fuels, the optimum ignition timing is 33° before top dead center (BTDC). Higher engine timing tends to go hand in hand with

better fuel efficiency: The higher the ignition timing, the better the fuel efficiency tends to be. The deration factor of 1.0 indicates that the engine operates at its full rating. However, if the methane number falls to 40, the timing must be changed to 22° BTDC to avoid detonation, and the derating factor of 0.9 means the engine output will be 900 hp. Engine output may also be derated as ambient temperature and altitude increase

Table 4. Derate factor/Engine timing Vs Methane Number

Derate Factor/Engine Timing vs Methane Number													
Methane Number	<30	30	35	40	45	50	55	60	65	70	75	80	83 to 100
Derate Factor Engine	0	0.9	0.9	0.9	1	1	1	1	1	1	1	1	1
Ignition Timing (BTDC)	-	19	21	22	23	24	26	27	28	30	31	32	33

From tables 2, 3 and 4, data is obtained, where there are differences in ignition timing (BTDC), in some of the Methane Number results. From the results of discussions and field checks, the ignition timing has been changed several times, which was originally 28, to 33. Currently, the engine condition itself only works at a load range of 40-60% of its capacity. From this, it could be that the engine is tripping because the ignition timing value is not in accordance with the manufacturer's instructions, which can cause detonation, which can cause engine shutdown. To analyze the fuel effects on engine performance after obtaining the LHV value, it is necessary to perform a theoretical calculation of the combustion air requirement per volume of gas, to obtain the LHV value of the air-fuel mixture. In naturally aspirated engines, the LHV value of the air-fuel mixture is compared to the LHV value of the fuel used by the engine manufacturer when creating the engine rating. Table 4. displays data from the theoretical calculation of energy output from fuel combustion between basic design and current conditions.

Table 5. Comparison of Relative Power Capability (RPC) Between Basic Design and Current Conditions (Basic Design)

Basic Design					
LHV A/F (To 905 Btu/scf Fuel)	***Btu/Scf***	86.2	86.2	86.2	86.2
LHV A/F Stoichometry	***Btu/Scf***	87.50	87.61	87.79	87.54
Output Energy	***bhp***	1125.53	1126.22	1128.63	1125.30
RPC (To 905 Btu/Scf Fuel)	***%***	101.58	101.64	101.86	101.56

Table 6. Comparison of Relative Power Capability (RPC) Between Basic Design and Current Conditions (Current Condition)

Current Condition					
LHV A/F (To 905 Btu/scf Fuel)	***Btu/Scf***	86.2	86.2	86.2	86.2
LHV A/F Stoichometry	***Btu/Scf***	87.29	86.73	86.71	86.61
Output Energy	***bhp***	1122.15	1115.04	1114.74	1113.43

RPC (To 905 Btu/Scf Fuel)	***%***	101.28	100.64	100.61	100.49

From table 5 and 6, it is found that the RPC in the current conditions still has an RPC value of 100%, so that theoretically the LHV value in the current fuel gas composition is still in accordance with the design energy output. To analyze more deeply, we collect data on gas composition every hour of the day, and analyze the fluctuations in changes in value that occur. Figures 2, 3, 4, 5, and 6 show fluctuations in changes in CO2, Methane, Hydrocarbon and Heating Value and Methane Number values in 1 day.

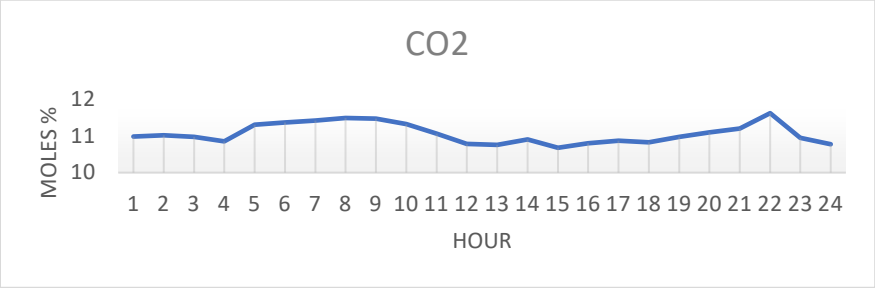


Figure 2. Hourly CO2 Parameter Reading

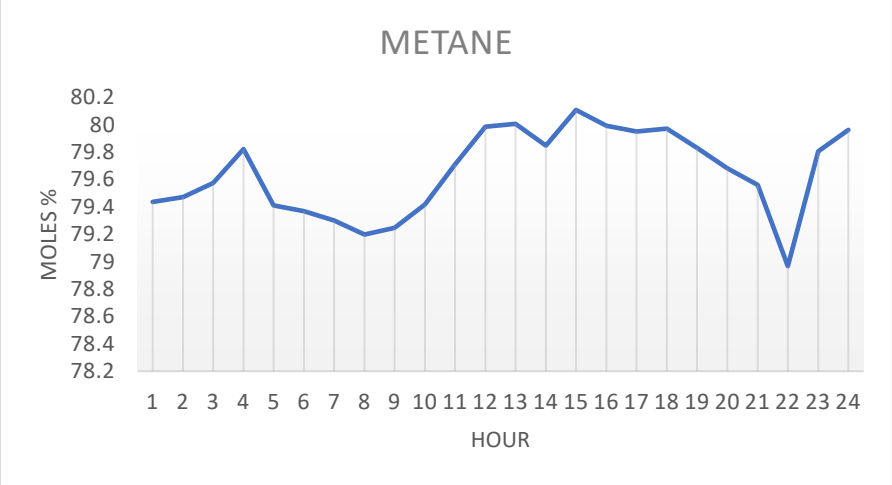


Figure 3. Hourly CH4 Parameter Reading

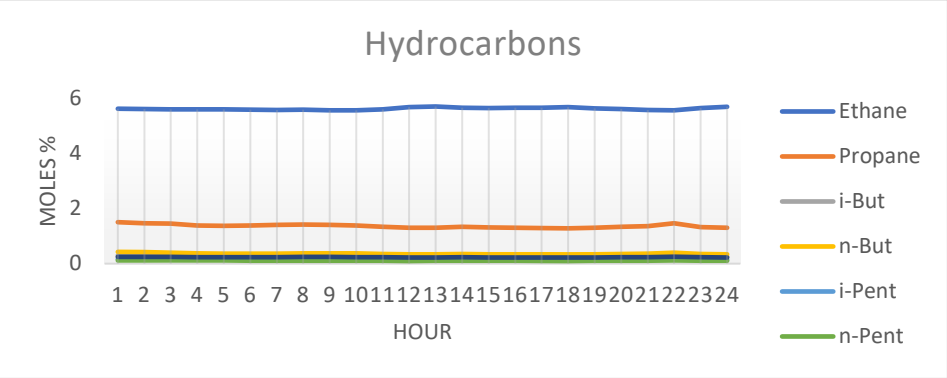


Figure 4. Hourly HC Parameter Reading

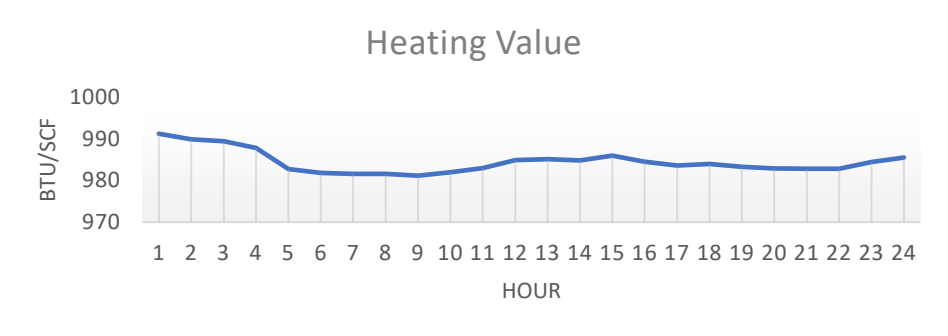


Figure 5. Hourly Heating Value Parameter Reading

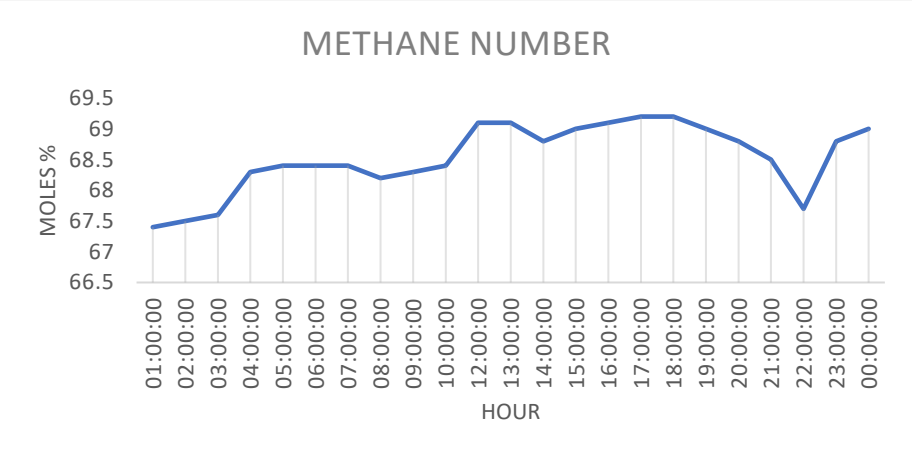


Figure 6. Hourly Methane Number Parameter Reading

From figures 2,3,5 and 6 there are varied fluctuations between the parameters CH4, CO2, Methane Number and Heating Value. Where as the CO2 value increases, the CH4 value, Heating Value and Methane number decrease, and vice versa. To analyze more deeply, data is collected every 2 minutes, for one hour, where an engine shutdown event occurs at that interval. Figures 7 and 8 display Co2 and Heating Value Parameter reading per 2 minutes.

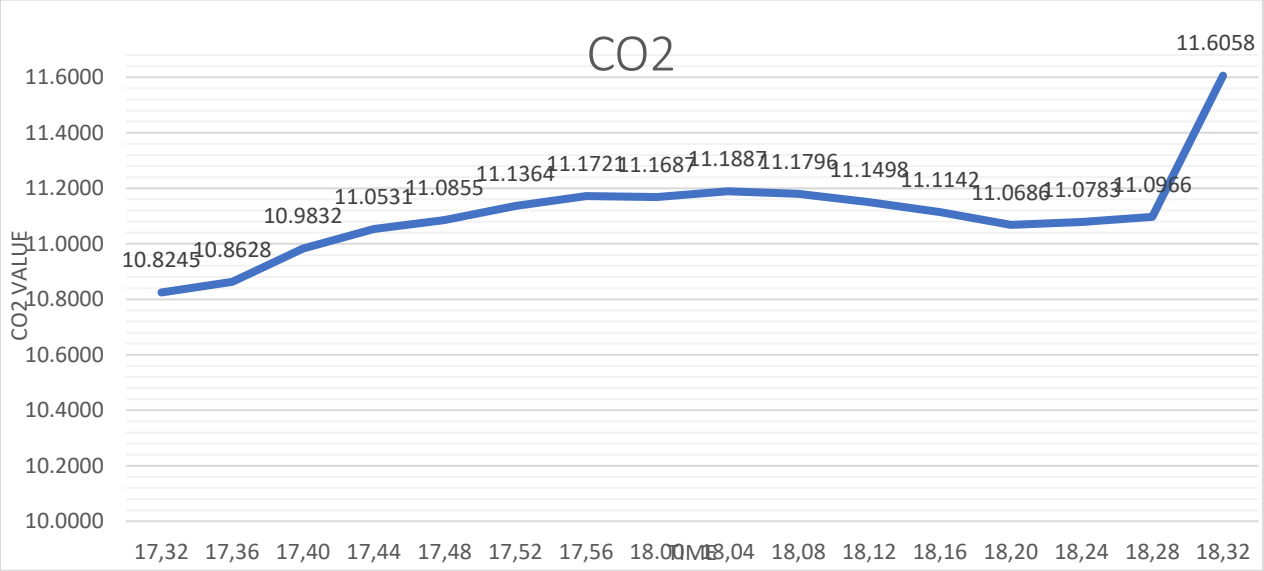


Figure 7. 2 Minutes Co2 Parameter Reading

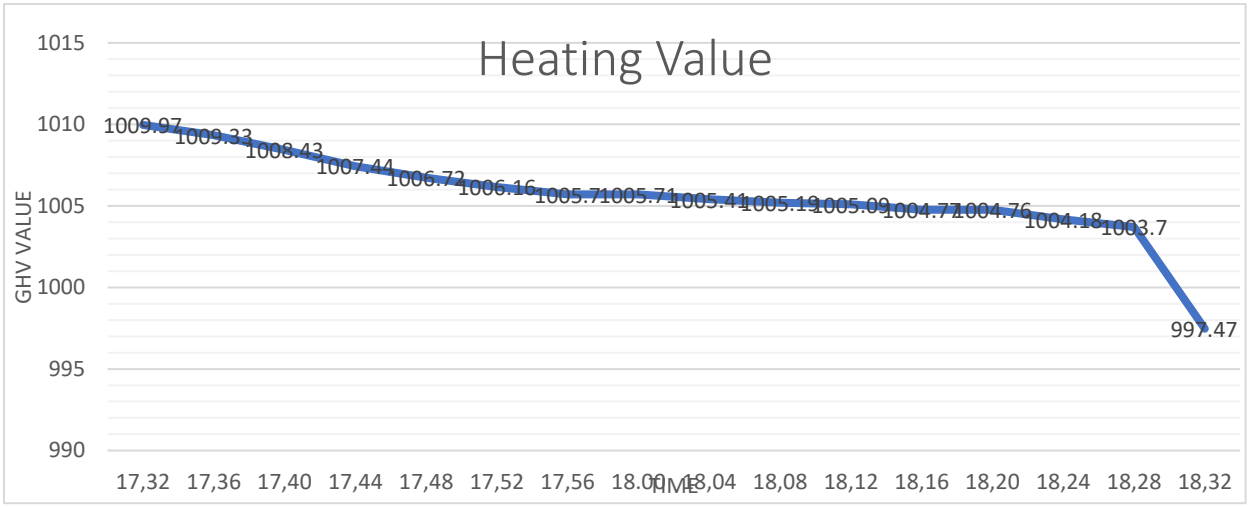


Figure 8. 2 Minutes, Heating Values Reading

From figure 7 and figure 8, data is obtained that in cycles per 2 minutes, there are fluctuations in the reading parameter on CO2 and heating value.

Tables 7 and 8 show data on the composition of fuel gas from gas source 1 and the results of the blend mix between gas sources 1 and 2.

Table 7. Current Fuel Gas Composition from Gas Source 1

Gas Compositions	**Units**	**Current Condition from Source 1**			
		Sample 1	***Sample 2***	***Sample 3***	***Sample 4***
H_2O	% Mole	0.0049	0.0049	0.0049	0.0052
CH_4	% Mole	90.6735	90.6537	90.5770	90.6103

C_2H_6	% Mole	3.1436	3.1448	3.1399	3.1476
C_3H_8	% Mole	0.9324	0.9332	0.9312	0.9355
i-C_4H_{10}	% Mole	0.2520	0.2524	0.2519	0.2537
n-C_4H_{10}	% Mole	0.2522	0.2532	0.2527	0.2548
i-C_5H_{12}	% Mole	0.1302	0.1305	0.1296	0.1323
n-C_5H_{12}	% Mole	0.0789	0.0792	0.0785	0.0805
C_6^+	% Mole	0.1552	0.1569	0.1579	0.1624
N_2	% Mole	0.2153	0.2154	0.2155	0.2145
CO_2	% Mole	4.1615	4.1755	4.2606	4.2029
H_2S	% Mole	0.0003	0.0003	0.0003	0.0003
O_2	% Mole	0.0000	0.0000	0.0000	0.0000
Total	% Mole	100,0000	100,0000	100,0000	100,0000
Methane Number	Btu/Scf	75.5	75.5	75.5	75.5
Wobbe Index	Btu/Scf	1167	1167	1165	1165
HHV	Btu/Scf	1030	1030	1029	1029
LHV	Btu/Scf	929	929	928	928

From Table 7, Gas Source 1 has a better methane number value, and is more stable for its composition value than gas source 1.

Table 8. Current Blend Mix Gas Composition from Gas Source 1 & 2

Gas Compositions	**Units**	**Current Condition from Blend Mix**			
		Sample 1	***Sample 2***	***Sample 3***	***Sample 4***
H_2O	% Mole	0.0001	0.0001	0.0002	0.0001
CH_4	% Mole	88.9743	88.8721	88.4280	89.1438
C_2H_6	% Mole	3.6968	3.7045	3.7917	3.6027
C_3H_8	% Mole	1.0953	1.1066	1.4039	1.0097
i-C_4H_{10}	% Mole	0.2706	0.2696	0.2972	0.2582
n-C_4H_{10}	% Mole	0.2906	0.2892	0.3222	0.2717
i-C_5H_{12}	% Mole	0.1264	0.1241	0.1343	0.1251
n-C_5H_{12}	% Mole	0.0630	0.0606	0.0659	0.0615
C_6^+	% Mole	0.1802	0.1786	0.1983	0.1804
N_2	% Mole	0.3607	0.3663	0.3933	0.3562
CO_2	% Mole	4.9420	5.0283	4.9650	4.9906
H_2S	% Mole	0.0000	0.0000	0.0000	0.0000
O_2	% Mole	0.0000	0.0000	0.0000	0.0000
Total	% Mole	100,0000	100,0000	100,0000	100,0000

Methane Number	Btu/Scf	74.5	74.6	72.8	75.1
Wobbe Index	Btu/Scf	1153	1151	1157	1151
HHV	Btu/Scf	1029	1028	1036	1025
LHV	Btu/Scf	928	927	935	925

From Table 8, the gas blend mix has a better methane number than gas source 2. So to maintain engine performance, there are two options to discuss, the first one, is to change the ignition timing setting value, the second is to use fuel gas which has better gas quality.

CONCLUSION

Gas engines can accept a wide range of gas quality, but the fluctuation of the fuel quality harms their performance. Rapid changes present serious engine control challenges and can have a substantial impact on engine performance and emissions. Total variation influences the way the engine must be fine-tuned. When an engine is operating at low load (low cylinder pressure), temperatures produced by compression of the charge are lower, which increases resistance to knock. Conversely, high load conditions increase the knock tendency. A change in the heating value of a fuel will change the air-fuel ratio required to maintain a certain emission level. Since carburetors are designed to maintain a constant air-fuel ratio (on a volume-to-volume basis) for a given engine load, any change in the heating value of the fuel will result in an incorrect air-fuel ratio for the desired emissions.

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