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The Effect of Carbon Dioxide Content-natural Gas on the Performance Characteristics of Engines: A Review

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Abstract: In this study, a survey of research papers on the effect of carbon dioxide/natural gas mixture on the performance characteristics of an Internal Combustion Engine (ICE) is carried out. Generally, the presence of high carbon dioxide content in natural gas reduces the heating value of the mixture when compared with pure natural gas. This leads to reduction in the burning velocity which ultimately affects the engine output and thermal efficiency. However, there is an improvement in the NO_X emissions while unburnt hydrocarbon and carbon monoxide are on the increase. Different techniques to improve engine performance were suggested and carried out. In addition to this, a direct injection fuel delivery system together with maintaining the air flow ratio is proposed as a way engine performance may be improved and emissions are reduced.

Key words: Direct injection, natural gas, CO_2, engine performance, emissions, nitrogen oxide

INTRODUCTION

With the increase in population growth, high demand has been placed on fossil fuels due to the improvement in the standard of living of the people, hence, the increase in the total energy consumption. It is expected that as the world population increases with time so will the energy consumption continue to increase as well. Figure 1 shows the energy trend as the world population increases yearly. The implication of this is that fossil fuel reserves are depleting rapidly and are predicted to be consumed in the near future. Not only that the price of this fossil fuel is increasing, but the burning of it generates noxious pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_X) and hydrocarbon (HC) which pose a serious threat to the very survival of life in the world (Das *et al*., 2000).

Stringent emission regulations are therefore introduced to reduce certain exhaust gas emissions so as to protect the environment from being polluted. However, researchers (Ghasemi and Djavareshkian, 2010; Anbese *et al*., 2011; Ismail and Nugroho, 2010; Al-Khairi *et al*., 2011) among others, do not stop in the search for alternative fuels for internal combustion engines with a view to improving the engine fuel economy and reduce exhaust emissions (Hu *et al*., 2009) by carrying out research studies on performance, combustion, emission and spray characteristics of alternative fuels.

Natural gas has emerged and proven to be one of the promising alternative fuels which when compressed for use in transportation and other applications, is known as Compressed Natural Gas (CNG). It is a gaseous fossil fuel that belongs to the clean fuels category (Korakianitis *et al*., 2011). Combustion of natural gas produces significantly lower emissions of carbon monoxide, carbon dioxide, non-methane hydrocarbon emissions and particulate matter when compared to diesel and gasoline in engine combustion processes (Korakianitis *et al*., 2011). Natural gas comprises of a mixture of various gas species which may differ from one source to another (Akansu *et al*., 2004). It predominantly contains 75-98% methane with small percentages of

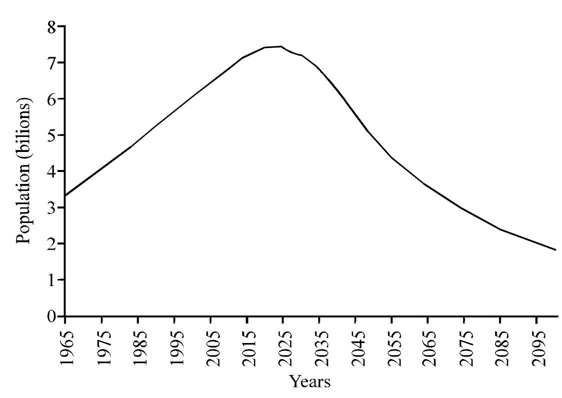

Fig. 1: World population with declining energy, 1965 to 2100 (Chefurka, 2007)

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Table 1: Composition and properties of the CNG used in Malaysia

Component	Symbol	Volumetric conc. (%)
Methane	CH_4	94.42
Ethane	C_2H_6	2.29
Propane	C_3H_8	0.03
Butane	C_4H_{10}	0.25
Nitrogen	N_2	0.44
Carbon dioxide	CO_2	0.57
Others	H_2O^+	2.00

Mohammed *et al.* (2011)

ethane, propane, butane, nitrogen, carbon dioxide and others. A detailed composition of Compressed Natural Gas (CNG) is shown in Table 1 (Mohammed *et al*., 2011). A natural gas fueled engine possesses high anti-knocking capability due to its high octane number which allows it to be operated at high compression ratios; thereby leading to further improvements in both power output and thermal efficiency; but this is also associated with an increase in the nitrogen oxides (NO_X) emissions. However, low emissions of carbon dioxide (CO_2), unburned hydrocarbons (HC) and carbon monoxide (CO) would be produced (Akansu *et al*., 2004). Natural gas is readily available and in abundance. Its availability can be seen in the South-east Asia proven and possible gas reserves estimated to be 182 Trillion cubic feet (Tcf) though undeveloped. Malaysia alone holds 37 Tcf of natural gas that has remained undeveloped as well. In the past, most of these gas fields were not economically valuable due to the presence of large quantities of CO_2 (25 to 89%).

Carbon dioxide is part of the constituents of natural gas reservoirs that are present in large quantities. Carbon dioxide gas (CO_2) is generally formed from a combination of two elements namely carbon and oxygen. It is majorly produced from combustion of coal or hydrocarbons, fermentation and decomposition of organic materials and breathing of humans and animals. Carbon dioxide is chemically inert in nature and slightly heavier than air. It has high specific heat capacity and does not support combustion. Methane is known to be the main constituent gaseous fuel (such as natural gas, biogas, landfill and sewage gas) that contributes to the heating value of fuels. The presence of high amounts of carbon dioxide in a mixture of natural gas/carbon dioxide can cause a lower heating value of the mixture when compared with pure natural gas. This, in turn, leads to a reduction in the burning velocity which ultimately affects the performance of the engine (Bari, 1996).

This study, therefore, reviewed the effect of high carbon dioxide content/natural gas on engine performance characteristics.

COMBUSTION, EMISSIONS AND PERFORMANCE OF ENGINES TO CARBON DIOXIDE PRESENCE IN FUEL

Extensive research studies have been carried out to determine alternative fuels that are best suited for Spark Ignition (SI) engines and other applications like vehicles. Research studies are yielding results that are very promising most especially from the fuel economy and exhaust emission reduction angles. Of the numerous works are the following:

Experimental work was carried out to study the effects of enhancing the methane concentration in biogas on the performance, emissions and combustion of a diesel engine modified to operate as a SI engine (Porpatham *et al*., 2012). At a constant engine speed of 1500 rpm, compression ratio of 13:1, various equivalence ratios ranging from rich to lean mixtures and using an intake swirl valve, the results of the tests showed that there is a considerable increase in the brake thermal efficiency with a decrease in the CO_2 concentration and thus increase in the brake power output. This is due to the increase in the methane concentration and more air intake into the cylinder. The consequences of this are faster combustion and higher temperatures and thus increasing thermal efficiency. With a decrease in the CO_2 concentration in the mixture, there is a significant reduction in the HC emissions particularly at lean mixture occasioned by complete combustion. By enhancing the methane concentration in the mixture, there was a significant improvement in the performance and reduction in emissions of Hydrocarbons (HC) particularly with lean mixtures.

The experimental work has studied the engine performance, combustion and exhaust emission of simulated biogas in a dual-fuel diesel engine (Henham and Makkar, 1998). This study has considered the use of simulated biogas of varying composition in a dual-fuel diesel engine. The SI engine was modified to use natural gas by changing the carburetor with gas-air mixer. The result of the experiments carried out at engine speed of 2000 rpm and torque of 40 Nm using NG:CO_2 mixture ranging from 100:0 to 40:60 showed that there is a 15-20% decrease in power due to a decrease in the volumetric efficiency because of the gaseous fuel and the lower flame speed of air-gas mixture compared with air-gasoline mixtures. With 37% NG substitution with CO_2, it was found that the efficiency was not much affected. However, at higher engine speeds, the efficiency was much affected when CO_2 substitution increased in the mixture. Exhaust gas temperature was affected more by NG substitution than by CO_2 addition except at maximum NG substitution where the exhaust gas temperature increased with CO_2 in the gas mixture. This was due to the large specific heat capacity possessed by CO_2 which also increased with temperature. Emissions of CO was not affected by the amount of CO_2 present in the mixture but was affected by the NG substitution. The in-cylinder pressure characteristics of the test engine at the engine operating condition showed that the peak pressure is not much affected when NG:CO_2 mixture was 1:1 compared with NG substitution. However at higher speeds the peak pressure reduced.

Experiments were conducted on a Ricardo engine using simulated biogas (natural gas and carbon dioxide) at different compression ratios, engine speeds and equivalent ratios with up to 40% carbon dioxide addition in the mixture (Huang and Crookes, 1998). The test results showed that the presence of CO_2 in natural gas has not only reduced the NO_X emissions but also enabled the compression ratio to be increased. Compression ratios ranging from 11:1 to 13:1 were found to be suitable for engine operation without knock. HC and NO_X levels were found to increase with the increase in the compression ratio. With CO_2 present, NO_X was tackled by lowering its emission level. However when the CO_2 fraction in the mixture decreased from 40%, the higher cylinder pressure obtained led to the increase in engine power and brake thermal efficiency by 2 and 3%, respectively and a decrease in the level of unburnt hydrocarbon. For lean fuel mixtures, a reduction in CO emissions was noticed and did not change with the presence of CO_2 in the mixture. Also at rich mixtures, CO emissions increased as the CO_2 fraction was increased above 30% due to incomplete combustion. At leaner fuel mixtures, all emissions were noticed to reduce even though the engine power and thermal efficiency were reduced particularly as the engine speed increased.

Also the replacement of carbon dioxide with nitrogen in biogas or natural gas was found to produce the same performance characteristics (Shrestha and Karim, 2001). The study was to predict the effects of the presence of diluents (CO_2 and N_2) with methane on SI engine performance over a range of operating conditions. When the effects of the concentration of the diluents in the fuel was predicted, the results of the experiments conducted to substantiate the predicted values were found to be in good agreement especially when the fractional concentration of the diluents in the fuel was lower than about 50%. More so, better agreement of the prediction was shown with nitrogen than with carbon dioxide as diluents.

The NO_X effect produced by the presence of carbon dioxide in natural gas is similar to the effect of EGR in spark ignition (SI) engines, compression ignition (CI) engines and homogenous charge compression ignition (HCCI) engines. EGR is one of the common techniques and effective methods to control in-cylinder NO_X emission in an internal combustion engine. The exhaust gases mainly consist of carbon dioxide, nitrogen etc and the mixture has a higher specific heat compared to atmospheric air. In a spark ignition (SI) engine, the recirculated inert exhaust gases displace some of the intake charge entering the combustion chamber, thereby reducing the combustion temperature and NO_X formation (Ibrahim and Bari, 2009). In a compression ignition (CI) engine, the inert exhaust gases replace some of the excess oxygen in the pre-combustion mixture, thereby decreasing the combustion rate. This automatically reduces the combustion temperature and NO_X formation. Several researchers have investigated the effect of EGR on engine performance and exhaust emissions (Hu *et al*., 2009; Ibrahim and Bari, 2009; Zheng *et al*., 2004; Fontana and Galloni, 2010; Sen *et al*., 2011; Agarwal *et al*., 2011; Peng *et al*., 2008). These studies have been performed in spark ignition (SI) engines, compression ignition (CI) engines and homogenous charge compression ignition (HCCI) engines and uniformly showed that the role of EGR was primarily to reduce NO_X emissions.

An experimental work was conducted and centered on how the engine performance varied with carbon dioxide content in biogas (Bari, 1996). In this study, gaseous mixture of natural gas and carbon dioxide of different compositions were used in a fumigated dual fuel engine to simulate biogas operated engine. From the results of the experiment, it was discovered that the flame temperature of diesel (1723°C) was high enough to initiate dissociation of CO_2 in the mixture into CO and O_2. With less than 30% of CO_2 in the mixture, the engine performance proved better with lower brake specific fuel consumption (bsfc) and diesel flow rates. This was due to the presence of dissociated CO which accelerated the burning rate of the mixture and the increase in O_2 concentration which enhanced the combustion of unburned carbon particles and reduced the ignition delay. However, with more than 30% of CO_2 in the mixture, CO_2 remained undissociated and therefore acted as inert gas which reduced the burning velocity of the mixture and thus resulting in an incomplete combustion.

ENGINE PERFORMANCE IMPROVEMENT TECHNIQUES

Exhaust emissions from an internal combustion engine fueled with various kinds of fuels can be

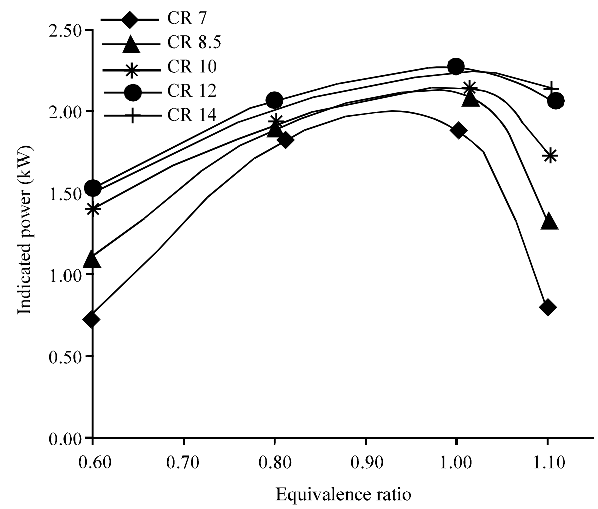

Fig. 2: Effect of CR on indicated power for different equivalence ratios (Shrestha and Karim, 2001)

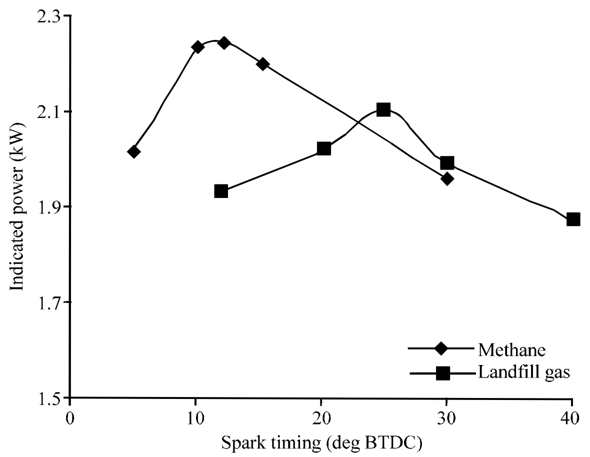

Fig. 3: Effect of spark timing on indicated power for methane and biogas (Shrestha and Karim, 2001)

controlled and engine performance parameters can as well be improved. The low engine performance that results when high CO_2 is present in a natural gas-carbon dioxide mixture can be overcome as suggested by numerous research results which suggested that increasing the Compression Ratio (CR) is a means of improving the performance of the engine when CO_2 is present (Huang and Crookes, 1998) even though there will be an increase in the emissions of NO_X, CO_2 and HC. However, NO_X emission is suppressed by the presence of the high CO_2 content in the fuel. In addition, it was found that the brake thermal efficiency increases with the increase in the compression ratio up to a critical value of 13:1. Above this value, little increase in the brake thermal efficiency was obtained (Huang and Crookes, 1998). So with compression ratios between 13:1 and 15:1 and with relative air-fuel ratio (RAFR) around the stoichiometric value (0.95 and 1.05), high power and thermal efficiency can be achieved (Huang and Crookes, 1998). Under these conditions, HC and CO emissions would be relatively low. Figure 2 shows significant power improvement due to increased compression ratio particularly for rich and lean limits.

Another technique to improve the low engine performance is by advancing the spark/ignition timing. Shrestha and Karim, 2001) reported to have improved the power output with increased diluents concentrations in the fuel mixture by advancing the spark timing especially when the diluent was carbon dioxide.

The reason being that the combustion duration of the mixture was long and to enable the slower flame speed to develop higher brake mean effective pressure (bmep). Figure 3 shows the effect of spark timing on engine power output when compared with natural gas. For maximum power to be obtained, spark timing has to be advanced.

CONCLUSION

It is quite obvious from the results of the experimental studies in the literature surveyed that there is a drop in engine performance which could be due to weak turbulence inside the combustion chamber occasioned by a large specific heat capacity of the diluents (i.e., CO_2) which absorbed more heat released and thus reduced the cylinder gas temperature. In addition the use of port injection or a carbureted fuel delivery system could also be a contributing factor as all the experimental studies were carried out using either gasoline engine modified to use gaseous fuels or diesel engine converted to operate as gas engine with provision to either use port injection or a carbureted fuel delivery system of which the penalty against it is reduction in power, volumetric efficiency and brake mean effective pressure.

Besides the above techniques of improving the engine performance, improving the turbulence within the cylinder could also bring about improvement in engine performance. With a direct injection fuel delivery system, the turbulence within the cylinder could be improved thus enabling faster combustion rates and also lower cycle to cycle variation. More so, the RAF ratio for natural gas fueled engine would be maintained while CO_2 is added to the mixture. This RAF ratio will be achieved by boosting the air flow into the cylinder with the aid of an air compressor. Thus, it can therefore be concluded that DI-CNG engine could be employed to investigate the effects of high CO_2 content-natural gas on the combustion performance and exhaust emission characteristics of the engine.

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REFERENCES

Agarwal, D., S.K. Singh and A.K. Agarwal, 2011. Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine. Applied Energy, 88: 2900-2907.

Akansu, S.O., Z. Dulger, N. Kahraman and T.N. Vezirogluc, 2004. Internal combustion engines fueled by natural gas-hydrogen mixtures. Int. J. Hydrogen Energy, 29: 1527-1539.

Al-Khairi, N.N., P. Naveenchandran and A.R.A. Aziz, 2011. Comparison of HCCI and SI characteristics on low load CNG-DI combustion. J. Applied Sci., 11: 1827-1832.

Anbese, Y.T., A.R.A. Aziz and Z.A.B.A. Karim, 2011. Flame development study at variable swirl level flows in a stratified CNG DI combustion engine using image processing technique. J. Applied Sci., 11: 1698-1706.

Bari, S., 1996. Effect of carbon dioxide on the performance of biogas/diesel duel-fuel engine. Renewab. Energy, 9: 1007-1010.

Chefurka, P., 2007. World energy and population trends to 2100. http://www. paulchefurka. ca/WEAP/WEAP. html

Das, L., R. Gulati and P.K. Gupta, 2000. A comparative evaluation of the performance characteristics of a spark ignition engine using hydrogen and compressed natural gas as alternative fuels. Int. J. Hydrogen Energy, 25: 783-793.

Fontana, G. and E. Galloni, 2010. Experimental analysis of a spark-ignition engine using exhaust gas recycle at WOT operation. Applied Energy, 87: 2187-2193.

Ghasemi, A. and M.H. Djavareshkian, 2010. Investigation of the effects of natural gas equivalence ratio and piston bowl flow field on combustion and pollutant formation of a DI dual fuel engine. J. Applied Sci., 10: 1369-1379.

Henham, A. and M.K. Makkar, 1998. Combustion of simulated biogas in a dual-fuel diesel engine. Energy Convers. Manage., 39: 2001-2009.

Hu, E., Z. Huang, B. Liu, J. Zheng and X. Gu, 2009. Experimental study on combustion characteristics of a spark ignition engine fueled with natural gas-hydrogen blends combining with EGR. Int. J. Hydrogen Energy, 34: 1035-1044.

Huang, J. and R.J. Crookes, 1998. Assessment of simulated biogas as a fuel for the spark ignition engine. Fuel, 77: 1793-1801.

Ibrahim, A. and S. Bari, 2009. A comparison between EGR and lean-burn strategies employed in a natural gas SI engine using a two-zone combustion model. Energy Convers. Manage., 50: 3129-3139.

Ismail, S.A.R. and T.F. Nugroho, 2010. Experimental and computational of engine cylinder pressure investigation on the port injection dedicated CNG engine development. J. Applied Sciences, 10: 107-115.

Korakianitis, T., A.M. Namasivayam and R.J. Crookes, 2011. Natural-gas fueled Spark-Ignition (SI) and Compression-Ignition (CI) engine performance and emissions. Prog. Energy Combust. Sci., 37: 89-112.

Mohammed, S.E.L., M.B. Baharom and A.R.A. Aziz, 2011. Analysis of engine characteristics and emissions fueled by in-situ mixing of small amount of hydrogen in CNG. Int. J. Hydr. Energy, 36: 4029-4037.

Peng, H., Y. Cui, L. Shi and K. Deng, 2008. Effect of Exhaust Gas Recirculation (EGR) on combustion and emissions during cold start of Direct Injection (DI) diesel engine. Energy, 33: 471-479.

Porpatham, E., A. Ramesh and B. Nagalingam, 2012. Effect of compression ratio on the performance and combustion of a biogas fuelled spark ignition engine. Fuel, 95: 247-256.

Sen, A.K., S.K. Ash, B. Huang and Z. Huang, 2011. Effect of exhaust gas recirculation on the cycle-to-cycle variations in a natural gas spark ignition engine. Applied Therm. Eng., 31: 2247-2253.

Shrestha, S.O.B. and G.A. Karim, 2001. Predicting the effects of the presence of diluents with methane on spark ignition engine performance. Applied Therm. Eng., 21: 331-342.

Zheng, M., G.T. Reader and J.G. Hawley, 2004. Diesel engine exhaust gas recirculation: A review on advanced and novel concepts. J. Energy Convers. Manage., 45: 883-900.