Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 11 (11): 2030-2035, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.2030.2035

Effect of Exhaust Gas Recirculation on the Dual Fuel Combustion of Gasoline and CNG by Compression Ignition

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Abstract: Homogeneous Charge Compression Ignition (HCCI) is a combustion process that promises the combination of diesel like efficiencies and very low NOx emissions. The major issues with HCCI are high heat release rates, lack of combustion control and high CO and HC emissions. Operating HCCI with two fuels of different properties and recirculation of exhaust gases are effective strategies of promoting and controlling autoignition. This study discusses the effects of EGR on the combustion characteristics of dual fuel HCCI of gasoline and CNG. The results show that EGR retards ignition timing, affects thermal efficiency and reduces heat release rates.

Key words: Combustion, HCCI, dual fuel, EGR, thermal efficiency

INTRODUCTION

The research on the internal combustion engines has been motivated in recent decades by the air pollution and its effect on environment and the energy scenario of the world. The development of advanced combustion techniques that would combine high thermal efficiencies and ultra low pollutant emission is yet to become technically and commercially viable. One of the combustion methods that look promising to meet the above requirements is Homogeneous Charge Compression Ignition (HCCI) (Najt and Foster, 1983).

HCCI has high thermal efficiencies on par with diesel engines due to low wall heat losses (Djavareshkian *et al*., 2008) and emits virtually no NOx. However, high heat release rates and lack of control combustion are the major issues that limit the load range of engine operable with HCCI combustion. The higher end of load is limited by rapid combustion that eventually results in knocking.

There are researches going on all over the world to find a practical means of combustion control. Several methods of combustion control such as high exhaust gas recirculation, operation with two different fuels, use of additives, multi stage injection, variable valve timing, controlling intake temperature and pressure, variable compression ratio and injection of reaction inhibitors. This paper discusses the effect of EGR on the combustion of gasoline and CNG which have different fuel properties such as octane number, autoignition temperature etcetera.

The use of two fuels having different autoignition temperatures is an effective strategy of achieving and controlling the combustion. While the fuel with lower autoignition temperature lowers the intake temperature required, the other fuel will burn later causing a slower overall combustion (Oakley *et al*., 2001; Topgu *et al*., 2006; Megaritis *et al*., 2007; Mack *et al*., 2005; Yao *et al*., 2006; Kong, 2007; Yao *et al*., 2006).

The task of intake air heating can be done using Exhaust Gas Recirculation (EGR). Retaining some of the exhaust gases in the cylinder can do this by negative valve overlap. This method is called internal EGR or residual gas trapping and can be achieved by Variable Valve Timing (VVT) with electronic control of lift and timing of the valves operation (Yap *et al*., 2005). The other method is to re-circulate exhaust gases externally called external EGR (Kim and Lee, 2006). The re-circulated gases have many effects on the charge characteristics and combustion phenomenon (Zhao *et al*., 2001).

When burnt gases are mixed with cooler inlet mixture of fuel and air the hot gases heat up the charge. This promotes autoignition and this is found to be responsible for ignition timing.

The charge dilution and the presence of chemical substances have some effects on the combustion duration than ignition timing. As dilution occurs some of O_2 is replaced with burnt gases. This suppresses any chemical reactions resulting in extended combustion and reduced Nox due to reduced oxygen availability (Zhao *et al*., 2001; Oakley *et al*., 2001a).

The heat capacity of the burnt gases is higher than that of the fresh charge and this has a very significant effect on increasing combustion duration and retarding ignition. Higher heat capacity is due to the higher specific heat values of carbon dioxide and water vapor.

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Replacement of some O_2 by CO_2 and H_2O reduces the ratio of specific heats (γ value) of the cylinder charge. This results in less temperature at the end of compression stroke resulting in ignition delay. Combustion duration increases due to the thermal cushioning caused by higher energy absorption and less pressure and heat release rates.

The mixing of EGR and charge in the cylinder is less complete and that creates charge and thermal stratification inside the cylinder (Ghasemi and Djavareshk, 2010). This feature of EGR can be used for control of combustion by thermal stratification (Morimoto *et al*., 2001).

MATERIALS AND METHODS

Operation of the engine in HCCI mode: As gasoline has a high octane number (RON 92) and the high auto ignition temperature, the intake air had to be heated to achieve HCCI combustion for the given engine of geometric compression ratio 14. Therefore, an intake air heater was added to the intake manifold of the engine and the charge was preheated (Lu *et al*., 2007; Kim and Lee, 2006). After several attempts of altering various engine operating parameters, HCCI combustion could be achieved at an inlet air temperature of 320°C.

The ignition of CNG that has high octane number is by the heat released by the combustion of gasoline. The CNG, that is otherwise difficult to autoignite, gets ignited by the heat liberated by the combustion of the gasoline (Yap *et al*., 2005).

The exhaust gas is re-circulated by using a valve which can be controlled by the engine ECU. The amount of EGR was varied from 0% to the limit of misfire that results at 53%.

The effects of EGR and CNG injection on the combustion has been studied at a constant engine speed of 1500 rpm and at a load of brake torque 8 Nm are presented in this study.

Experimental setup: The experiment setup is based on the CNG Direct injection engine of specifications listed in Table 1. Figure 1 shows the schematic of the experimental setup with the added components to the existing CNG DI engine.

The CNG DI engine was suitably modified to operate with two fuels at a time and on HCCI mode. To supply the gasoline to the engine, a manifold injection system was added to the existing CNG DI engine. As intake air is to be heated to achieve HCCI combustion, an electrical air heater of 2.4 kW had been added to the intake system.

Gasoline injection system: The gasoline injection system consists of a fuel pump, fuel rail, fuel pressure regulator and an injector. The fuel was injected into the intake manifold at a pressure of 3 bars. The injector was powered by an injector driver circuit and controlled by the pulse train generated by a LABVIEW program.

CNG direct injection: CNG was injected by the existing direct injection system at a fuel rail pressure of 12 bars. CNG DI engine has the piston with a bowl on its top which creates stratified CNG concentration for late injection timings (From the angle of inlet valve closure,

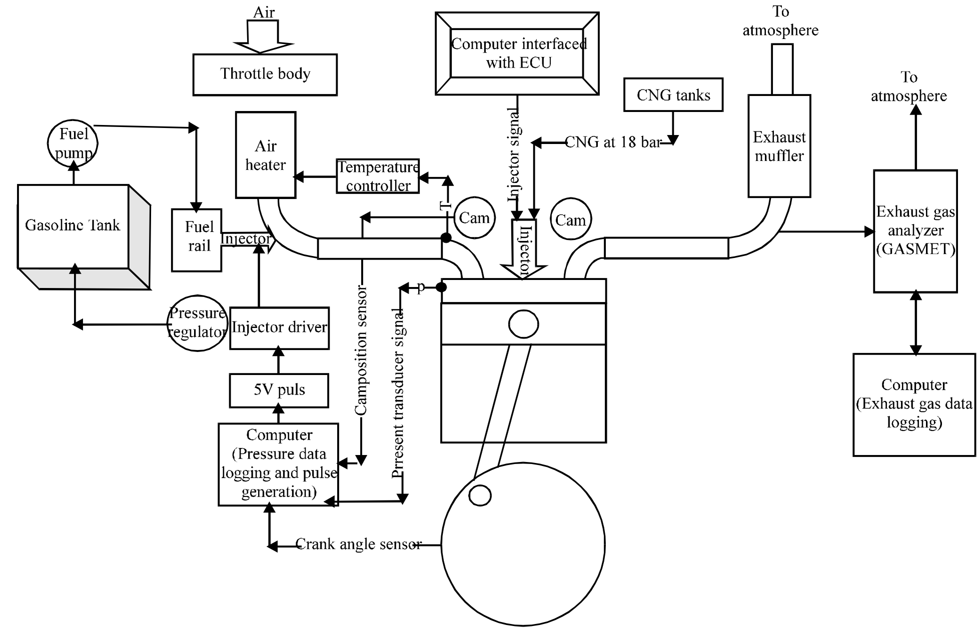

Fig. 1: Experimental setup of the dual fuel HCCI engine test facility

Table 1: Engine specifications and operating parameters

Factor	Values
Engine specifications	
Bore	88 mm
Stroke	132 mm
Compression ratio	14
Exhaust valve open (EVO)	45°BBDC
Exhaust valve Closed (EVC)	10°ATDC
Inlet valve open (IVO)	12°BTDC
Inlet valve closed (IVC)	48°ABDC
Operating parameters	
Brake torque	8±0.5 Nm
Gasoline flow rate	395 g h r^{-1}
CNG flow rate	225 g h r^{-1}
CNG-injection at:	300 BTDC

132 to 60° BTDC). However, early injection timings (300° BTDC) had resulted in relatively homogeneous mixtures.

RESULTS AND DISCUSSION

There are significant effects of EGR on both gasoline and dual fuel HCCI combustion as shown in Fig. 2 and 3. The rate of pressure rise and peak pressure are affected the presence of CNG in the mixture. When CNG is added to the charge and with no EGR, it results in higher peak pressures and pressure rise rates as shown in Fig. 3. However, EGR reduces the peak pressures and retards the autoignition timing for both gasoline and dual fuel combustion. The EGR results in higher peak pressures within 30% and further EGR reduces peak pressures. The effect of EGR is more significant after 30 to 53%.

From the heat release analysis as shown in Fig. 2 and 3, it is observed that dual fuel HCCI has higher heat release rates than the single fuel gasoline combustion. Up to 30% of EGR, the heat release rate increases for the gasoline HCCI and beyond that EGR reduces the heat release rate. The presence of CNG in the mixture results in earlier autoignition of the whole mixture at no EGR conditions. However, the EGR reduces heat release rates and retards the autoignition for the both single and dual fuel combustion. However, in all the cases, at a given EGR percentage, the dual fuel combustion has higher heat release rates than the single fuel gasoline HCCI.

The exhaust temperature is higher for dual fuel HCCI, as the heat release rates are higher. Figure 4 shows the effect of EGR on the exhaust temperature of gasoline and dual fuel HCCI combustion. The exhaust temperature is reduced at 20% which may be due to the increase in specific heat capacity of the mixture. However, the effect of increased specific heat capacity diminishes and there is corresponding increment in exhaust temperature as the EGR rate increases.

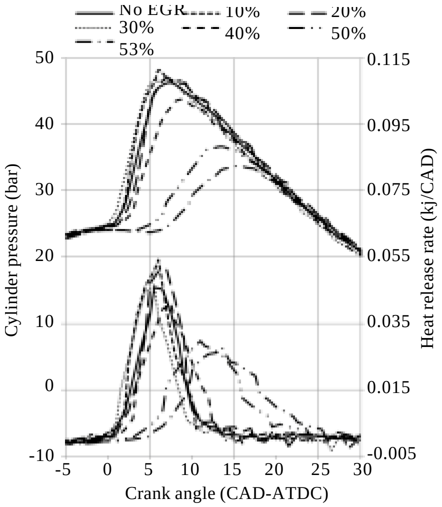

Fig. 2: Pressure and heat release rates for gasoline HCCI combustion with various levels of EGR

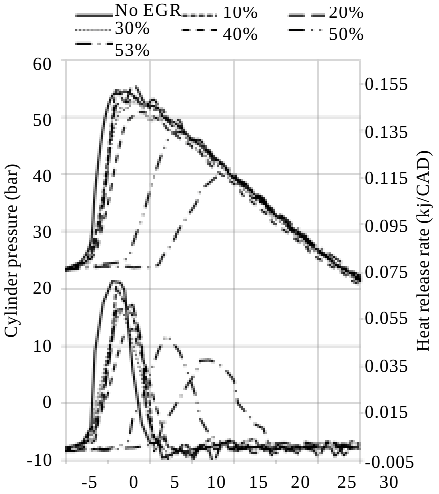

Fig. 3: Pressure and heat release rates for gasoline and CNG dual fuel HCCI combustion with various levels of EGR

From Fig. 5, it can be seen that EGR helps improve the of variation of IMEP. There is marginal difference effect of EGR on the exhaust temperature of gasoline and

The exhaust temperature is higher for dual fuel HCCI, as the heat release rates are higher. Figure 4 shows the

between the single fuel and dual fuel HCCI and for both the cases the COV is very high at 10% EGR. Figure 6 shows that the indicated thermal efficiency is higher regardless of EGR for single fuel gasoline HCCI combustion and this may be due to poor combustion efficiencies with dual fuel operation as shown in Fig. 7.

When EGR is increased the up to 10% it improves the combustion efficiency and then decreases again. It may be due to the heat capacity effect. More than 10% EGR may result increased in energy absorption and reduced oxygen availability.

Figure 8 and 9 show the mass fraction burned and the effect of EGR on the combustion process. The combustion process is rapid for the dual fuel combustion and EGR retards the combustion. Up to certain point around 0.85, there is rapid combustion for dual fuel HCCI and after that the curve becomes flat. This indicates that the combustion of CNG depends on the heat released by the heat liberated by the combustion of gasoline.

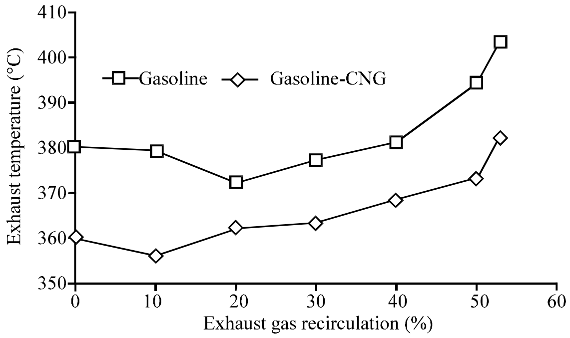

Fig. 4: Exhaust gas temperatures with single and dual fuel operation

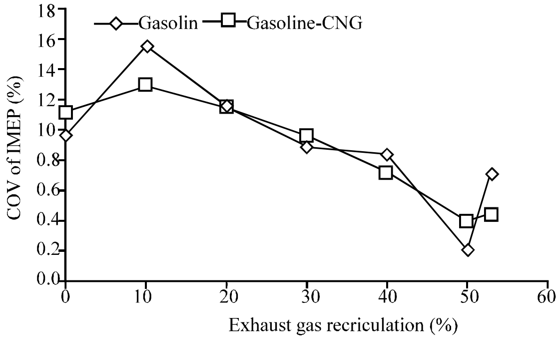

Fig. 5: Co-efficient of variation of IMEP

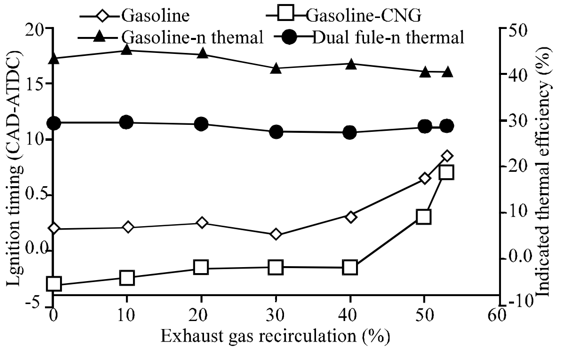

Fig. 6: Effect of EGR and ignition timing on indicated thermal efficiency

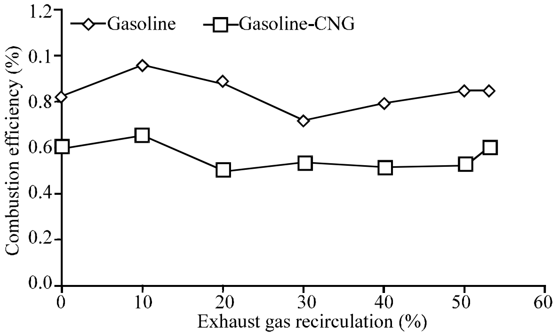

Fig. 7: Role of EGR on combustion efficiency

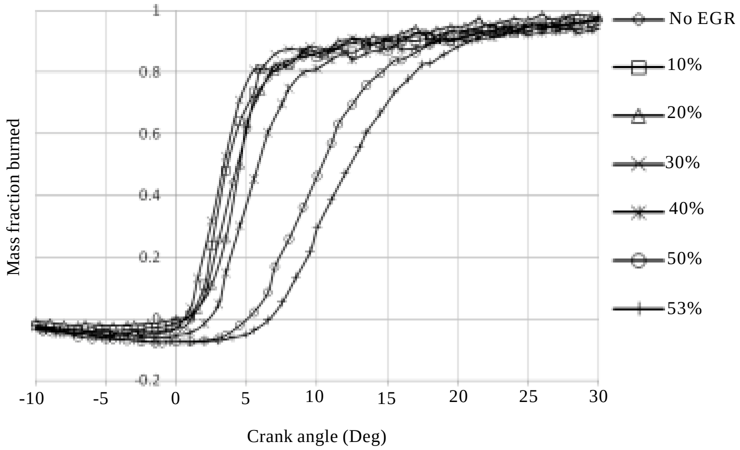

Fig. 8: Effect of EGR on the mass fraction burned with single fuel of gasoline

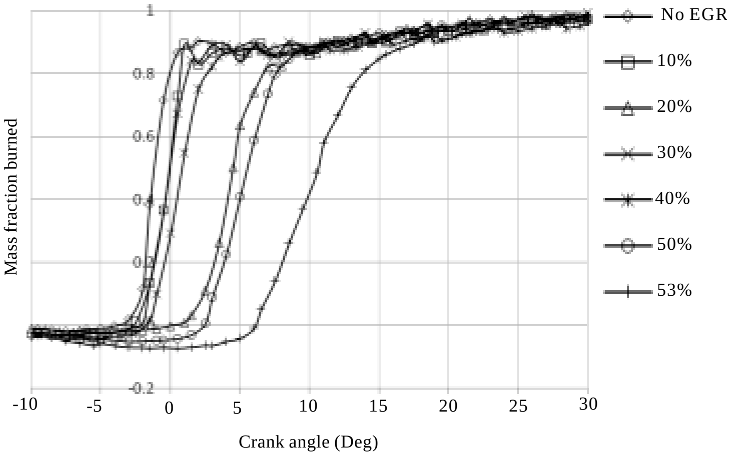

Fig. 9: Effect of EGR on the mass fraction burned with gasoline and CNG

CONCLUSION

Gasoline and CNG dual fuel HCCI results in higher peak pressures and higher heat release rates compared to single fuel gasoline HCCI combustion. Dual fuel operation was found to be of no significant benefits at the given proportion of mass flow rates of gasoline and CNG. EGR reduces the peak pressures and a heat release rate for both and this effect is more significant above 30% of EGR. About 10 of EGR addition increase the thermal efficiency and combustion efficiency. Overall, EGR is found to be an effective tool in reducing the characteristic high heat release rates of HCCI for both single fuel and dual fuel combustion with similar trends.

REFERENCES

Djavareshkian, M.H., F. Talati, A. Ghasemi and S. Sohrabi, 2008. Multidimensional combustion simulation and analytical solution of wall heat conduction in di diesel engine. J. Applied Sci., 8: 3806-3818.

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.

Kim, D.S. and C.S. Lee, 2006. Improved emission characteristics of HCCI engine by various premixed fuels and cooled EGR. Fuel, 85: 695-704.

Kong, S.C., 2007. A Study of natural gas/DME combustion in HCCI engines using CFD with detailed chemical kinetics. Fuel, 86: 1483-1489.

Lu, X., L. Ji, L. Zu, Y. Hou, C. Huang and Z. Huang, 2007. Experimental study and chemical analysis of n-heptane homogeneous charge compression ignition combustion with port injection of reaction inhibitors. Combustion Flame, 149: 261-270.

Mack, J.H., D.L. Flowers, B.A. Buchholz and R.W. Dibble, 2005. Investigation of HCCI combustion of diethyl ether and ethanol mixtures using carbon 14 tracing and numerical simulations. Proc. Combustion Institute, 30: 2693-2700.

Megaritis, A., D. Yapb and M.L. Wyszynskic, 2007. Effect of water blending on bioethanol HCCI combustion with forced induction and residual gas trapping. Energy, 32: 2396-2400.

Morimoto, S.S., Y. Kawabata, T. Sakurai and T. Amano, 2001. Operating characteristics of a natural gas-fired homogeneous charge compression ignition engine (Performance improvement using EGR). SAE Paper, 2001-01-1034, 2001.

Najt, P.M. and D.E. Foster, 1983. Compression-ignited homogeneous charge combustion. SAE Paper 830264. http://papers.sae.org/830264.

Oakley, A., H. Zhao, N. Ladommatos and T. Ma, 2001. Dilution effects on the Controlled Auto Ignition (CAI) combustion of hydrocarbon and alcohol fuels. SAE Trans., 110: 2086-2099.

Oakley, A., H. Zhao, N. Ladommatos and T. Ma, 2001. Experimental studies on Controlled Auto-Ignition (CAI) combustion of gasoline in a 4-stroke engine. SAE Trans., 110: 1062-1075.

Topgu, T., H.S. Yucesu, C. Cinar and A. Koca, 2006. The effects of ethanol–unleaded gasoline blends and ignition timing on engine performance and exhaust emissions. Renewable Energy, 31: 2534-2542.

Yao, M., Z. Chen, Z. Zheng, B. Zhang and Y. Xing, 2006. Study on the controlling strategies of homogeneous charge compression ignition combustion with fuel of Dimethyl ether and methanol. Fuel, 85: 2046-2056.

Yao, M., Z. Zheng and J. Qin, 2006. Experimental study on homogeneous charge compression ignition combustion with fuel of dimethyl ether and natural gas. J. Eng. Gas Turbines Power, 128: 414-420.

Yap, D., J. Karlovsky, A. Megaritis, M.L. Wyszynski and H. Xu, 2005. An investigation into propane Homogeneous Charge Compression Ignition (HCCI) engine operation with residual gas trapping. Fuel, 84: 2372-2379.

Zhao, H., Z. Peng, J. Williams and N. Ladommatos, 2001. Understanding the effects of recycled burnt gases on the Controlled Auto Ignition (CAI) combustion in four stroke gasoline engines. SAE Trans., 110: 2100-2113.