에너지공학, 제14권 제4호(2005)
Journal of Energy Engineering, Vol. 14, No. 4, pp. 226~231 (2005)

Basic Performance Characteristics of HCCI (Homogeneous Charge Compression Ignition) Engine

Gyeung Ho Choi*, Yon Jong Chung, Ji Moon Kim***, Robert W. Dibble**** and Sung Bin Han****,†**

**Dept. of Mechanical & Automotive Engineering, Keimyung University, Korea*
***Dept. of Automotive Engineering, Daegue Mirae College, Korea*
****Dept. of Mechanical System Design, Myongji College, Korea*
*****Dept. of Mechanical Engineering, University of California at Berkeley, U.S.A.*
******Dept. of Mechanical Engineering, Induk Institute of Technology, Korea*
(Received 25 July 2005, Accepted 5 December 2005)

Abstract — Essentially a combination of spark ignition and compression ignition engines, the HCCI engine exhibits low NOx and Particulate Matter (PM) emissions as well as high efficiency under part load. This paper is concerned with the Homogeneous Charge Compression Ignition (HCCI) engine as a new concept in engines and a power source for future automotive applications. In this research, a 4 cylinder diesel engine was converted into a HCCI engine, and propane was used as the fuel. The purpose of this research is to show the effects of fuel flow rate and the temperature of the intake manifold on the performance and exhaust of an HCCI engine.

Key words: Homogeneous charge compression ignition engine, NOx, CO, HC

1. Introduction

As a new class of engines, the Homogeneous Charge Compression Ignition (HCCI) engine is receiving high praises. In addition to the use of hydrogen, electricity, solar power, etc., Society of Automotive Engineers (SAE) is considering the HCCI engine as a new concept in internal combustion engines for possible use in future automotive applications.

The main concept of HCCI combustion can be described as the combination of spark ignition and compression ignition engines. Combustion in a compression ignition engine takes place at a high temperature region where auto-ignition of the fuel becomes possible, and the HCCI engine uses a homogeneous fuel/air mixture. In addition, a relatively low-pressure fuel injection method is used to supply fuel to the intake manifold. Because HCCI combustion takes places simultaneously at several locations, the variation between combustion cycles is very small. Also, the mixture is combusted at an almost homogeneous state. Through HCCI combustion, unstable flame propagation can be avoided.

The greatest advantage of HCCI is the fact that NOx and PM (particulate matter) emissions are low and efficiency is high under part load[1]. However, the disadvantage of HCCI is that, under different load conditions, limits of Indicated Mean Effective Pressure (IMEP) exist and HC and CO emission are relatively high.

NOx reduction of 90~98% compared to a conventional diesel engine is clearly one of the most attractive features of the HCCI engine. Such NOx reductions are possible because a high temperature region does not exist within the combustion chamber. HCCI combustion occurs in the presence of a homogeneous air/fuel ratio, and in such cases, the mixture is very lean and the combustion temperature is very low compared to a diesel or a spark ignition engine[2]-[5].

Au *et al.*[6] conducted research on the effects of the

†To whom correspondence should be addressed.
Department of Mechanical Engineering, Induk Institute of Technology, San 76 Wolgye-Dong, Nowon-Gu, Seoul 139-747, Korea
Tel: 02-950-7545
E-mail: sungbinhan@induk.ac.kr

equivalence ratio and EGR in HCCI engine operation. In addition, Flowers *et al.*[7] conducted HCCI research using a production engine. They used a 1.6 liter VW engine that used the preheated intake air method to achieve HCCI combustion, and it was shown that part load efficiency increased from 14% to 34%.

Aoyama *et al.*[8] was involved in an interesting HCCI research using what they called Premixed Charge Compression Ignition (PCCI). Their research concerned the comparison of PCCI, diesel, and Gasoline Direct Injection (GDI). PCCI had the lowest fuel consumption at the optimized air/fuel ratio. While PCCI also had the lowest NOx exhaust, its HC exhaust was higher.

Because diesel emission regulations will become stricter in the future, diesel engine users are taking a high interest in HCCI combustion. HCCI combustion is also known to reduce NOx emissions even for spark ignition engines at low load. However, the development of an HCCI fuel or additives is needed.

HCCI combustion takes place by compressing the air, fuel, and the recirculated exhaust gas to cause auto-ignition, and as a result, a heat releasing reaction takes place simultaneously in different locations at the same equivalence ratio. Unlike a traditional diesel engine, the HCCI engine does not have a clearly defined flame front, and unlike a spark ignition engine, a localized, high-temperature reaction zone does not exist. Consequently, HCCI combustion is well spread out, and the low-temperature combustion takes place very rapidly[9][10].

In this research, a multi-cylinder diesel engine was modified into a HCCI engine, and propane was used as the fuel. The primary interest of this research is to investigate the effects of fuel flow rate and intake manifold temperature on the HCCI engine's performance and exhaust gas emission. Such research will be a valuable source of information for the development of the HCCI engine.

2. Experimental Apparatus and Procedure

For the HCCI engine experiment, a 4-cylinder, 1896 cc diesel engine (Volkswagen Turbo Direct Injection) was used. The in-cylinder fuel injectors have been removed from the combustion chamber and have been replaced with inserts containing water-cooled quartz pressure transducers. The combustion chamber has not been modified for this current work.

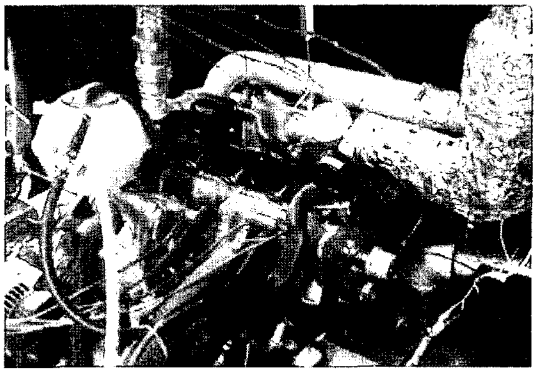

Fig. 1. Photo of experimental setup.

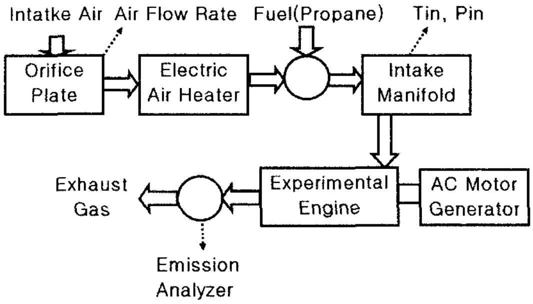

Fig. 2. Schematic diagram of experimental engine.

Table 1. Engine specifications.

Item	Specification
Displacement	1.896 *l*
Bore	79.5 mm
Stroke	95.5 mm
Connecting rod length	144.0 mm
Compression ratio	18.8 : 1
Piston Geometry	Bowl

Fig. 1 shows a photo of the experimental setup, and Fig. 2 shows the schematic diagram.

The engine's specifications are shown in Table 1.

For the experiment, a turbo charged engine was modified into a naturally aspirated engine, and in order to preheat the intake air, an 18 kW electric heater was used. Energy required for the preheating was not included in the efficiency calculations. A dynamometer was used to control and measure the load to the engine, and thermocouples were used to measure the temperatures of the intake, exhaust, coolant, engine oil, and other parts.

The engine used in the test was run at 1800 RPM, and in order to cause auto-ignition in the HCCI engine at the given fuel rate and compression ratio, the intake air had to preheated. The degree of preheating varies depending on compression ratio, manifold pressure, fuel composition, and air/fuel ratio.

The pressure within the cylinder was measured using a pressure sensor, and the obtained pressure value was used to determine fuel rate, heat release rate, IMEP, and other combustion characteristics. Also, an exhaust gas analyzer was used to measure NOx, HC, CO, and other gasses in the exhaust.

Through experimentation, propane was used as fuel in the experiment. Intake temperature and fuel-air equivalence ratio were used as variable parameters in this experiment. Fuel-air equivalence ratios of 0.3, 0.33, 0.36, and 0.39 were used, and intake temperature was varied between 102 and 140.

3. Experimental Results and Discussion

The measured performances of an HCCI engine, converted from a 4-cylinder compression ignition engine, are shown in Fig. 3~Fig. 12. The Fig. 3 shows torque as a function of intake temperature, for various fuel-air equivalence ratios. The reduction of intake temperature resulted in the increase of engine output; reduction of intake temperature causes air density, and consequently torque, to increase. The increase in torque due to reduction in intake temperature is a general trend shown also for compression ignition and spark ignition engines. The figure also shows that torque increases with the fuel-air equivalence ratio. The increase in torque occurs because an increase in the fuel-air equivalence ratio indicates an increase in the relative amount of fuel compared to air.

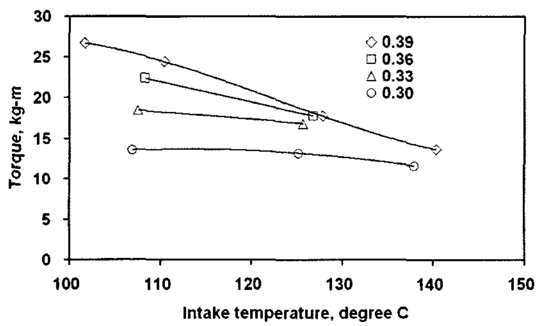

Fig. 3. Torque vs. intake temperature for varying fuel-air equivalence ratios.

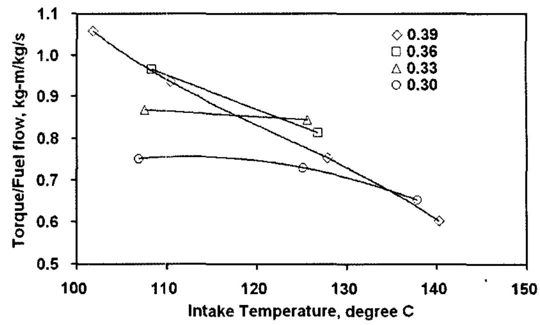

Fig. 4. Torque/fuel flow rate vs. intake temperature for varying fuel-air equivalence ratios.

Fuel-air equivalence ratios of 0.28~0.42 and intake temperatures of 102, 108, 126, and 139°C were used in the experiment. As stated previously, the results once again show that low-temperature intake mixture leads to increased torque. Because HCCI engines in general are sensitive to temperature variations of the mixture, even a minor temperature variation in the intake mixture can lead to misfire. The figure also shows that as fuel-air equivalence ratio becomes leaner, torque tends to decrease due to unstable combustion.

Fig. 4 shows torque/fuel flow rate as a function of intake temperature for varying fuel-air equivalence ratios. Intake temperatures of 102~140°C were used, and the fuel-air equivalence ratios of 0.3, 0.33, 0.36, and 0.39 were used. The trend shown in torque/fuel flow rate vs. intake temperature is similar to that of torque vs. intake temperature. However, the results from this experiment confirm that the torque increase depends largely on fuel flow rate. Also in this case, reduction in intake temperature generally brings about a decrease in torque/fuel flow rate. As the fuel-air equivalence ratio becomes lower, unstable combustion leads to slightly lower than expected values. Generally during combustion, a very lean mixture leads to unstable combustion and consequently misfires, but in the case of HCCI combustion, ignition takes place simultaneously at different locations within the com-

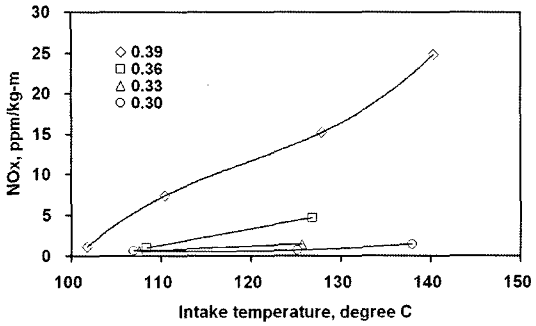

Fig. 5. NOx vs. intake temperature for varying fuel-air equivalence ratios.

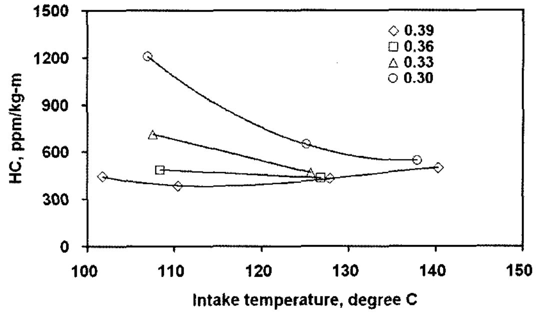

Fig. 7. HC vs. intake temperature for varying fuel-air equivalence ratios.

bustion chamber and therefore results in relatively small variations between combustion cycles. Also, the mixture is combusted in an almost homogeneous state, resulting in the avoidance of unstable flame propagation, and as the figure shows, there is a subsequent decrease in torque/fuel flow rate in the regions of lean combustion.

Fig. 5 shows NOx emissions vs. intake temperature for varying fuel-air equivalence ratio values, and Fig. 6 shows NOx emissions vs. fuel-air equivalence ratio for varying intake temperatures.

The results from the experiment show that, with the exception of the fuel-air equivalence ratio of 0.39, NOx emission was very low under all test conditions. One of the most attractive features of HCCI is the reduction in NOx; as expected, NOx emissions were almost zero in the lean region with equivalence ratios of 0.3 and 0.33. Upon varying the equivalence ratio under constant temperature, NOx emissions are even lower for lean mixtures, as shown in Fig. 6. Such reductions in NOx emissions are likely attributed to the absence of a high temperature region within the combustion chamber and also the generally homogeneous equivalence ratios.

Such research regarding lean mixtures should provide even better results with the addition of EGR.

Fig. 7 shows the experimental results of HC emissions vs. intake temperature for varying fuel-air equivalence ratios. Fig. 8 shows HC emissions vs. fuel-air equivalence ratio for varying intake temperatures. Judging from the increase in HC emissions in the lean combustion region, it appears that combustion is slightly unstable in this region. However, HC levels are not too high because the HCCI engine exhibits homogeneous combustion.

Fig. 9 shows CO emissions vs. intake temperature for varying fuel-air equivalence ratios, and Fig. 10 shows CO emissions vs. fuel-air equivalence ratio for varying intake temperatures. The results shows that at constant equivalence ratios, CO emissions tend to

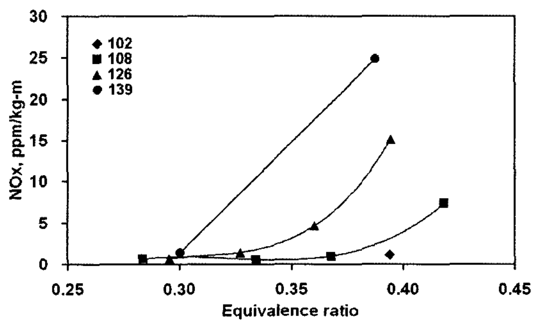

Fig. 6. NOx vs. fuel-air equivalence ratio for varying intake temperatures.

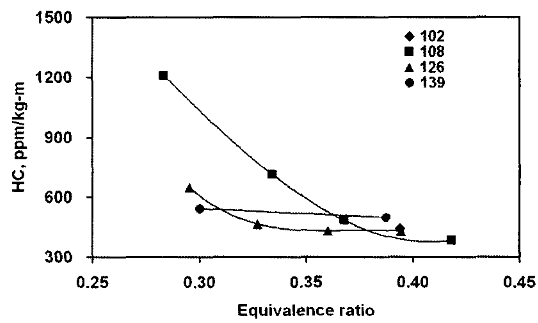

Fig. 8. HC vs. fuel-air equivalence ratio for varying intake temperatures.

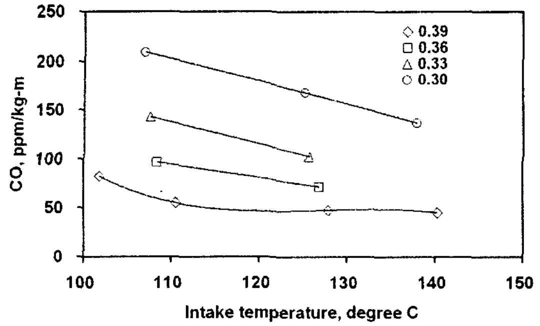

Fig. 9. CO vs. intake temperature for varying fuel-air equivalence ratios.

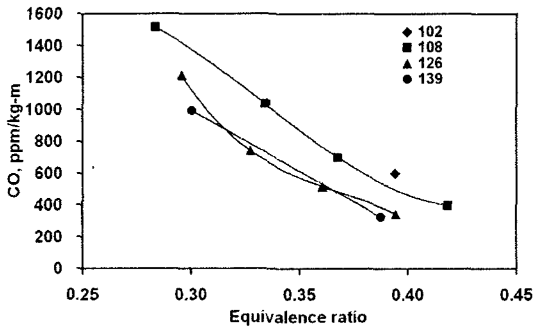

Fig. 10. CO vs. equivalence ratio for varying intake temperatures.

decrease slightly for increasing intake temperatures. One of the greatest disadvantages of the HCCI engine is the increase in HC and CO emissions. One reason for the increased emissions is the low operating temperature within the cylinders. In general, if there is a reduction in the temperature of combustion gases, post-combustion oxidation rate falls and also HC and CO emissions increase.

4. Conclusion

In this experiment, a 4-cylinder diesel engine was converted into a HCCI engine, and propane was used as fuel. The main parameters of the experiment were fuel flow rate and intake temperature, and the effects of such parameters on the performance and exhaust emissions of the HCCI engine were investigated. The results are as follows.

(1) Torque increases as fuel-air equivalence ratio increases, and it also increases as intake temperature decreases. The dependence of torque/fuel flow rate on intake temperature is similar to that of torque vs. intake temperature. Because HCCI engines are sensitive to temperature changes of the mixture, even a slight variation in the temperature of the intake mixture can result in unstable combustion and therefore torque reduction.

(2) Plots of NOx emissions vs. fuel-air equivalence ratio at constant temperatures show that NOx emissions are even less at lower intake temperatures. Such reduction in NOx are likely attributed to the absence of a high temperature region within the combustion chamber and also the generally homogeneous equivalence ratios.

(3) HC and CO emissions decrease slightly with increasing intake temperature, and the presence HC and CO is in part due to the low temperatures within the cylinders of the HCCI engine.

Acknowledgement

This work was supported by grant No. RTI04-03-02 from the Regional Technology Innovation Program of the Ministry of Commerce, Industry and Energy (MOCIE).

References

1. Hwang, J.S.; Ha, J.S.; No, S.Y. "Spray characteristics of DME in conditions of common rail injection system (II)", International Journal of Automotive Technology, 2003, 4, 3, 119-124.
2. Akagawa, H.; Miyamoto, T.; Harada, A.; Sasaki, S.; Shimazame, N.; Tsujimura, K. "Approaches to solve problems of the premixed lean combustion", SAE Paper 1999-01-0183, 1999.
3. Iwabuchi, Y.; Kawai, K.; Shoji, T.; Takeda, Y. "Trial of new concept diesel combustion system-premixed compression-ignited combustion", SAE Paper 1999-01-0185, 1999.
4. Christensen, M.; Johansson, B. "Homogeneous charge compression ignition with water injection", SAE Paper 1999-01-0182, 1999.
5. Odaka, M.; Suzuki, H.; Koike, N.; Ishii, H. "Search for optimizing control method of homogeneous charge diesel combustion", SAE Paper 1999-01-0184, 1999).
6. Au, M.; Girard, J.W.; Dibble, R.; Flowers, D.; Aceves, S.M.; Frias, J.M.; Smith, J.R.; Seibel, C.;

Maas, U. "1.9-liter four-cylinder HCCI engine operation with exhaust gas recirculation", SAE Paper 2001-01-1894, 2001.
7. Flowers, D.; Aceves, S.M.; Frias, J.M.; Smith, J.R.; Au, M.; Girard, J.; Dibble, R. "Operation of a four-cylinder 1.9l propane fueled homogeneous charge compression ignition engine: basic operating characteristics and cylinder-to-cylinder effects", SAE Paper 2001-01-1895, 2001.
8. Aoyama, T.; Hattori, Y.; Mizutta, J.; Sato, Y. "An experimental study on premixed-charge compression ignition gasoline engine", SAE Paper 960081, 1996.
9. Shimazaki, N.; Akagawa, H.; Tsujimura, K. "An experimental study of premixed lean diesel combustion process", SAE Paper 1999-01-0181, 1999.
10. Stanglmaier, R.H.; Roberts, C.E. "Homogeneous charge compression ignition (HCCI): benefits, compromises, and future engine applications", SAE Paper 1999-01-3682, 1999.