Development of the Constant Volume Spray Combustion Chamber for Ignition Quality Testing of Diesel-like Fuel

Chih-Yung Wu[1], Kun-Ho Chen[2], Tien-Chiu Hsu[3]
Department of Mechanics and Automation, Kao Yuan University
Advanced Engine Research Center
Kaohsiung, Taiwan

[2]Advanced Engine Research Center, Kao Yuan University
Kaohsiung, Taiwan

[3]Department of Power Mechanical Engineering, National Formosa University
Yunlin, Taiwan

1 Introductions

Due to the overconsumption of fossil fuels, the rise in total CO_2 emissions as well as the toxic emissions becomes an imperious crisis of humankind. Biomass is a potential energy source that can mitigate the problems of global warming due to greenhouse gas emission and energy consumption. For heavy duty transportation, biodiesel can be used in traditional diesel engines. Distinct form the fossil diesel, the properties in terms of viscosity, density, flash point, cetane rating and heat value of biodiesel varies with the feedstock and the transesterification process. Moreover, diesel additives or oxygenate species is also applied to increase diesel's performance in terms of cetane rating, metal corrosion inhibitors and emission control. In our previous study, the bio-crude is blended with fossil diesel via emulsification process and directly used in a diesel engine. The results show that the combustion is enhanced by the microexplosion of fuel droplet, and both the cylinder peak pressure and heat release rate are increased [1]. In the near future, the use of alternative fuels that contains complex composition can be more versatile and attractive. It becomes essential to develop combustion techniques and to understand chemical and physical properties of combustion process for such kind of fuels.

It is well known that both low temperature combustion [2] and homogeneous charge compression ignition techniques [3] depends on autoignition of fuel to control engine operation. In the past, a standard ignition quality tester (IQT^{TM}) [4] has been proposed. Different to shock tube or rapid compression machine which is restricted to premixed gas phase mixtures. IQT^{TM} can be used to measure the ignition for low volatility fuel. The numerical and experimental studies of fuel autoignition in the IQT system have also been proposed [5],[6]. In the present study, a constant volume spray combustion testing device was fabricated to measure the ignition quality for diesel-like or low volatility liquid fuel. A lower pressure fuel supply system is used and five thermocouples to measure temperature in the present system. The testing chamber has also been verified with blended n-

Correspondence to:chihyungwu@gmail.com

Hexadecane with an assigned CN =100 and 2, 2, 4, 4, 6, 8, 8- Heptamethylnonane with an assigned CN = 15.

2 Methodology

The experimental setup is schematically shown in Figure 1. The testing chamber consists of a constant volume chamber that is 254 cc. It is heated by a 3.7kW electric heater. The pressure and composition of oxidizer are controlled using a PID controller to precisely measure the pressure of air. The pressure of combustion is measured by a PCB piezotronics pressure sensor, and the temperature in the reaction chamber is monitored by four K-type thermocouples. The signal is logged using NI USB-6259, and the sampling rate is 500 kHz. The fuel injector used in the present study is a commercial single-hole injector manufactured by BOSCH for GDI engines. To maintain the fuel pressure at a high, steady level, the fuel was supplied with a specially designed high pressure tank instead of a fuel pump, and the fuel tank was pressurized by helium at 100 bars. Both the injector and the pressure sensor was mounted in the reaction chamber with water jacket to avoid thermal damage. A PC is used to control the experiment conditions including chamber pressure, temperature of gas, injection timing. The experimental results are also recorded by the computer via NI LabVIEW VI system. The experimental conditions for device examination are listed in Table 1, and the cetane number (CN) is calculated by determining the mixture of n-Hexadecane and 2, 2, 4, 4, 6, 8, 8- Heptamethylnonane.

The spray characteristics of fuel injector were measured using laser-based flow visualization. A dual-rod Nd:YAG laser (New Wave Research, Solo III-15) was used as an illumination device, and the power of the wavelength was 5 0mJ and 532 nm. The dual-rod Nd:YAG laser can generate double sequential pulses within a short time interval for spray velocity measurement. The laser beam passes through three cylindrical lenses and is introduced into the pressure chamber in the form of a sheet with a thickness of 0.5 mm. With precise timing control, the planar information of the fuel spray could be obtained.

3 Results and Discussions

Before combustion chamber design, the fuel injector has been well studied to avoid spray impingement on the wall of chamber. As shown in Figure 2, the spray characteristics can be observed using laser based flow visualization. The spray angle and penetration distance can also be measured exactly according to sequential photographs. The fuel injector must be manufactured to deliver an accurately metered fuel quantity with a high repetition rate for each pulse. The effect of pressure difference on the mass flow rate and liner flow curve is examined. The mean fuel per injection versus injection duration time for different pressure difference is shown in Figure 3.

As the fuel injected into the reaction chamber, the pressure signal induced by the autoignition of fuel can be measured. The heat release rate can be evaluated by eq. (1)

$$\frac{dQ_{hr}}{dt} = \frac{1}{\gamma - 1} V \frac{dP}{dt} \qquad (1)$$

Where V = 254 cubic centimeter and γ is assumed as 1.36. By integration of eq (1), the total heat release rate can be obtained. As shown in Figure 4, the total heat release rate for variant cetane number fuel is shown. The ignition delay can also be evaluated base on the evolution of total heat release rate and shown in Figure 5. The non-linear relationship between ignition delay time and the Cetane Number is found and provided by the following equation (2):

$$\text{Ignition delay} = -\,0.56\ln(\text{Cetane Number}) + 3.95 \qquad (2)$$

4 Conclusions

In the present study, a constant volume spray combustion testing device was fabricated to measure the ignition quality for diesel-like or low volatility liquid fuel. The testing chamber has been well verified using blended n-Hexadecane and 2, 2, 4, 4, 6, 8, 8- Heptamethylnonane with variant cetane number. According to the preliminary results, the device can be used to measure cetane number for low volatility fuels and to calculate the heat release rate based on measured pressure.

5. Acknowledgement

This research was supported by the Ministry of Economic Affairs of Taiwan under Grant numbers 103-EC-17-A-16-S1-169 and the Ministry of Science and Technology of Taiwan under Grant numbers MOST 103-2221-E-244-005.

Table 1 experimental conditions

CN	N-Hexadecane (vol%)	Heptamethylnonane (vol%)	LHV (MJ/kg)
15	0.0	100.0	43.9
20	5.9	94.1	43.9
30	17.7	82.3	43.9
40	29.4	70.6	43.9
50	41.2	58.8	43.9
60	53.0	47.0	43.9
70	64.8	35.2	43.9
80	76.5	23.5	43.9
90	88.3	11.7	43.9
100	100.0	0.0	43.9

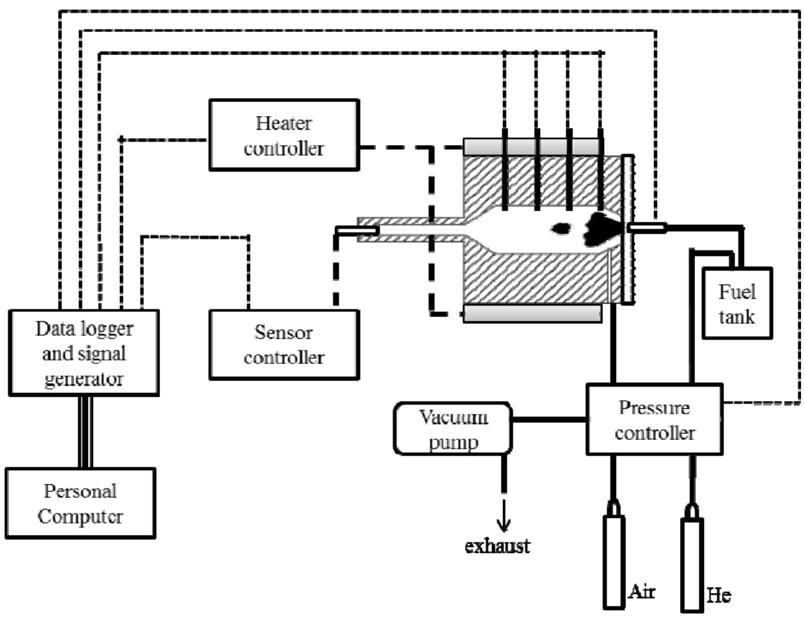

Figure 1 Schematic illusion of experiment apparatus.

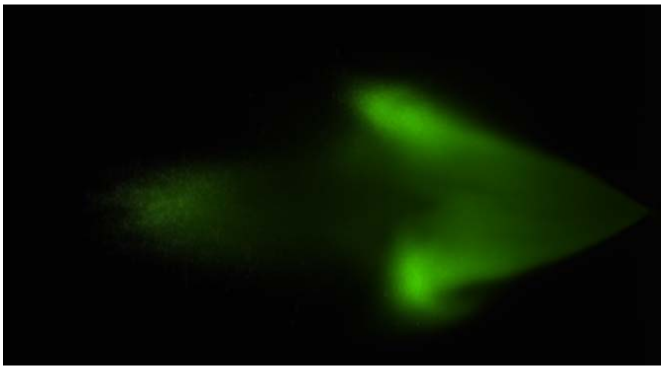

Figure 2 Selected laser-based spray visualization

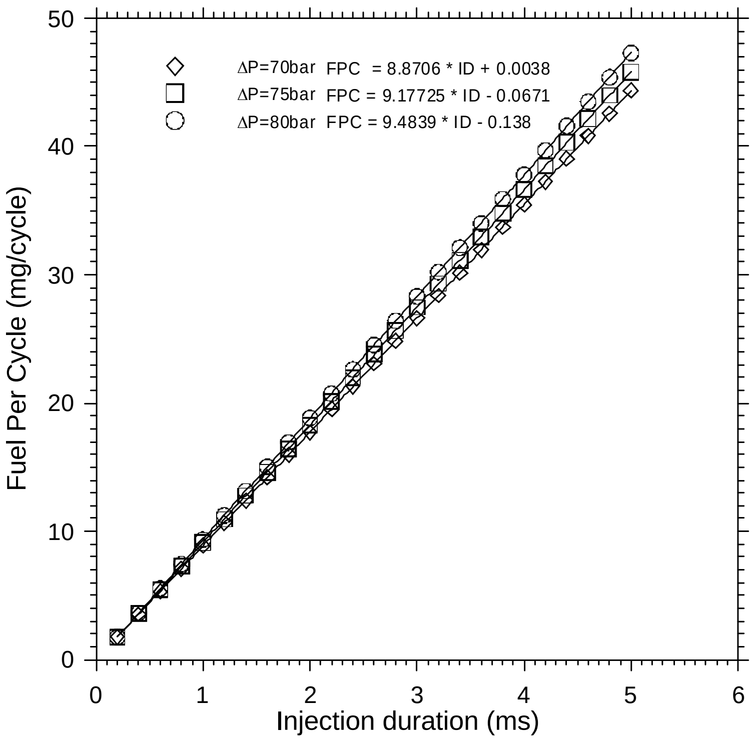

Figure 3 Effect of the ambient pressure on the mass flow rate with constant fuel pressure

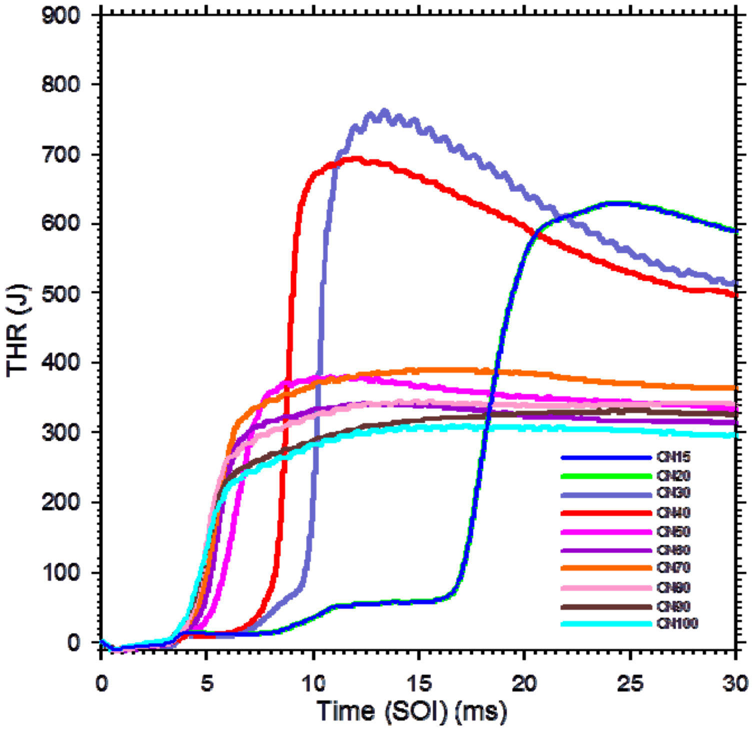

Figure 4 Total heat release rate for variant cetane number fuel

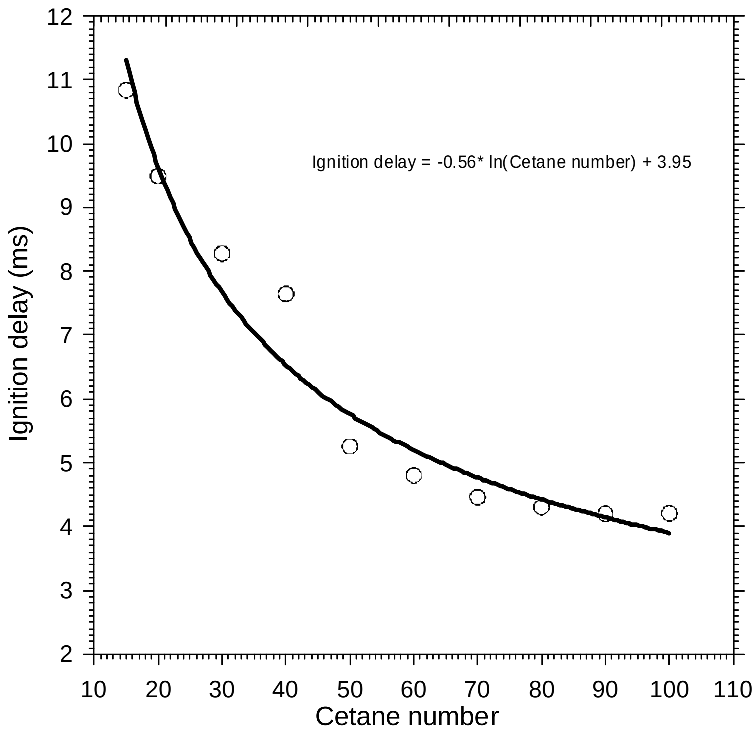

Figure 5 Ignition delay versus cetane number with the ignition quality testing chamber.

References

[1] Yang SI, Hsu TC, Wu CY, Chen KH, Hsu YL, Li YH. (2014). Application of biomass fast pyrolysis part II: The effects that bio-pyrolysis oil has on the performance of diesel engines. Energ. 66:172.

[2] Imtenan S, Varman M, Masjuki HH, Kalam MA, Sajjad H, Arbab MI, Rizwanul Fattah IM. (2014). Impact of low temperature combustion attaining strategies on diesel engine emissions for diesel and biodiesels: A review. Energ. Convers. Manage. 80:329.

[3] Bendu H, Murugan S. (2014). Homogeneous charge compression ignition (HCCI) combustion: Mixture preparation and control strategies in diesel engines. Renew. Sust. Energ. Rev. 38:732.

[4] Allard LN, Webster GD, Hole NJ, Ryan IIITW, Ott D, Fairbridge CW. (1996) Diesel fuel ignition quality as determined in the Ignition Quality Tester (IQT). SAE technical paper series 961182.

[5] Bogin GE, Dean AM, DeFilippo A, Chen JY, Chin G, Luecke J, Ratcliff MA, Zigler BT. (2010). Modeling the Fuel Spray and Combustion Process of the Ignition Quality Tester with KIVA-3V. Conference Paper: NREL/CP-540-46738

[6] Bogin GE, DeFilippo A, Chen JY, Chin G, Luecke J, Ratcliff MA, Zigler BT, Dean AM. (2011). Numerical and Experimental Investigation of n-Heptane Autoignition in the Ignition Quality Tester (IQT). Energ Fuels. 25:5562.