

# High Speed Gas Sampling System for Engine Cylinder Emission Analyses

Nuri Yucel, Salih Karaaslan, Ender Hepkaya, and Nureddin Dinler

**Abstract**—In this study, high speed gas sampling system was used to collect gas samples in the engine cylinder. C<sub>1</sub>-C<sub>5</sub> based HC components behavior in the engine cylinder were investigated experimentally during the flame period. Model GSD-10 fast response gas sampling system was used to sample gas in the cylinder. The high speed gas sampling valve mounted on the engine cylinder was connected to the gas chromatograph instrument directly, and samplings were continuously gathered at the intended crank shaft angle ranges. The electro-magnetic valve lift time was controlled by setting a time-lag from the TDC reference point of the engine crank angle. Crank pulses were provided by crank pulse generator. The generator consists of a slit disc mounted on the engine shaft and a photo-electric pick-up. It was designed to generate the crank pulse (360 pulses/rev) and the reference pulse (1 pulse/rev). In cylinder gas samples were taken for 10-15 degree intervals after the ignition. Samples taken during the flame period were approximately 60 degrees of crank angle after the spark plug ignited. In this study, Agilent 7890A Gas Chromatography (GC) system was employed to analyze C<sub>1</sub>-C<sub>5</sub> HC component of the sampled gas from the engine cylinder. GC-FID (Flame Ionization Detector) analysis method was utilized to investigate hydrocarbon components. Response time of hydrocarbon components were listed. HC components variation with respect to crank angle were plotted and interpreted.

**Index Terms**—Gas sampling system, in cylinder engine emissions, hc components.

## I. INTRODUCTION

The use of a fast flame-ionization detector (FID) system for measuring hydrocarbon (HC) levels in spark ignition engine cylinder was described in the study of N. Ladommatos [1]. The system in that study [1] was used to measure the hydrocarbon levels in each engine cycle. Results were obtained that in-cylinder excursion of air-fuel ratio after sudden throttle opening and the amount of trapped combustion residuals in the cylinder during low-load low-speed running, and the effect of residuals on combustion [1].

Exhaust HC emissions from spark ignition engines play an important role in photochemical reactions. In the study of I. Shizuo and L. Tamotsu, the source of unburned HCs from engines were considered as quenching in the crevices of combustion chamber as well as oil layer and deposits on the combustion chamber wall [2]. The behavior of unburned HCs

on the combustion chamber wall was investigated with using a high speed gas sampling technique during the expansion and exhaust processes [2]. A. C. Alkidas [3] reviewed the studies investigating sources as combustion chamber crevices and reducing techniques of HC emissions. The researcher concluded that combustion and flow field inside the combustion chamber effect the burned gas concentration in the crevices strongly [3]. Effect of fuel composition in spark ignition engine is an important parameter to reduce hydrocarbon emissions. H. Zuohua *et al.* [4] used a single cylinder engine which was operated on hexane-gasoline and xylene-gasoline blends. Total hydrocarbon emissions have been measured by FID. It was shown that Henry's constant, diffusion coefficient and distillation temperature of fuel components dominate the mass of in-cylinder unburned hydrocarbons were influenced by the fuel. The compositions of the fuel greatly influence the engine out HC emissions [4]. N. A. Henein and M. K. Tagomori [5] presented the source of tailpipe HC emissions during cold start. They used port injected gasoline engines. They investigated the parameters which influences tailpipe HC emissions on cycle basis. Fast response flame ionization detector (FFID) measurements of engine out HC emissions were given. At the end of the study, the approaches for reducing cold-start operation tailpipe and engine-out HC emissions were discussed [5]. In another experimental study, effects of very lean fuel/air ratio conditions on HC emissions were investigated [6]. FFID used to measure high concentrations of HC emissions for two test cycles. For the same burned mass fraction, the cycles have different IMEP and different HC emissions due to partial combustion and varying degrees of post flame oxidation inside the cylinder [6]. In a study of B.M. Broderick and I.S. Marnane [7], hydrocarbon concentrations of ambient, fuel and hourly road were measured on a heavy traffic junction for more than 45 days. They concluded that the HC concentration of ambient air (suspected unburned fuel components) and fuel's relative HC concentrations were in good agreement, when the major partial oxidation products were ignored [7]. C. S. McEnally *et al.* [8] investigated CH<sub>4</sub> to C<sub>12</sub>H<sub>26</sub> alkanes, volume fraction of soot, major components and temperature in methane/air non-premixed flames. The fuel used in the study was separately doped with 5000 ppm of five heptanes isomers [8]. W. Yang [9] used Sokken model GSD-10 type unit in order to investigate the hydrocarbon oxidation studies on Homogeneous Charge Compression Ignition (HCCI) engine. Also, he developed a kinetic model to predict pressure, temperature and heat release rate for the same engine. The results of experimental and model studies were in good agreement.

In our study, Ricardo research engine was used with the

Manuscript received November 25, 2012; revised January 29, 2013. This work was supported by the Scientific Technological Research Council of Turkey under Grant of Support Programme for Scientific and Technological Research Project (Project Code: 109M420).

The authors are with Faculty of Engineering Mechanical Engineering, Department Ankara Turkiye, Gazi University, Turkey (e-mail: nuyucel@gazi.edu.tr; karaaslansalih@gazi.edu.tr; ndinler@gazi.edu.tr).

in-line sampling system with GC analyzer. C<sub>1</sub>-C<sub>5</sub> based HC components in the cylinder were collected via the high speed gas sampling system. Then the instantaneous samples were analyzed by using GC-FID technology.

## II. EXPERIMENTAL SETUP

All experiments were carried out on a single cylinder Ricardo E6 research engine which has variable compression ratio. The engine was coupled to a DC dynamometer with DV-300 control module to provide free motoring and firing capabilities. The control module is wired to a dynamometer with a rated maximum speed of 3000 rpm. While engine runs, the dynamometer could be maintained the speed within  $\pm 5$  rpm of the preset conditions. A flywheel is connected to the crankshaft in order to reduce cyclic variation and speed fluctuations caused by the intermittent combustion events. The specifications of Ricardo E6 research engine are listed on Table I.

TABLE I: RICARDO E6 ENGINE SPECIFICATIONS

Cylinder Diameter	76.2 mm
Stroke	111.1 mm
Displacement Volume	0.507 l
Max. Rev. number	3000 rpm
Maximum Power	9.4 kW
Max. Cylinder Pressure	150 bar
Fuel	Gasoline
Static Ignition	25° BTDC
Compression Ratio	variable

Engine in-cylinder gases were extracted at the prespecified crank angle ranges during combustion period by using high speed gas sampling system. Model GSD-10 gas sampling system basically consist of two main units: a high speed electro-magnetic gas sampling needle valve and a high speed magnetic exciter which is designed to provide the exciting current to the needle valve. In addition to that, the auxiliary instrumentations are supplied with the main unit. Those are:

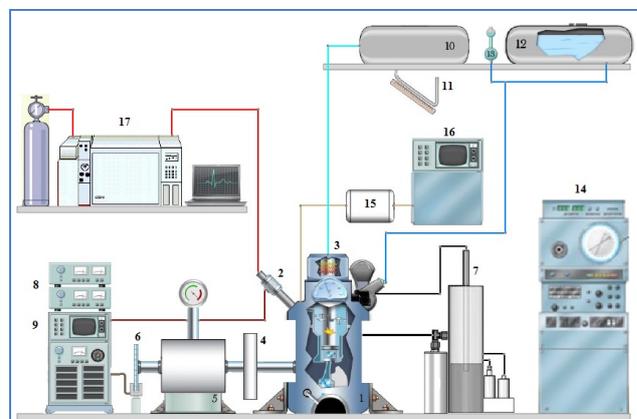
- A sampling valve controller which enables the sampling valve to operate at the desired timing.
- A crank pulse generator which provides the crank angle information to the controller.
- A valve motion detector which monitors valve lifts wave-forms or performances of the sampling valve.

Accordingly, the high speed gas sampling system, model GSD-10, is completed with;

1. Electro-magnetic gas sampling needle valve,
2. High speed magnetic exciter,
3. Sampling valve controller,
4. Crank pulse generator with slit disc,
5. Valve motion detector,
6. Rack.

The sampling valve controller provides the control signal to the exciter. The controller can amplify and shape pulse signals from the photo-electric pick-up mounted on engine shaft. In the case of four cycle engine, this unit has an additional function which TDC reference pulse can be divided into half. The lift time of the sampling valve is controlled by setting a time-lag from the reference TDC point.

The generator, which is consisted of a slit disc and a photo-electric pick-up, is designed to generate the crank pulse (360 pulses/rev) and the reference pulse (1 pulse/rev). These pulses are provided to the valve controller, and then amplified and shaped. The detector detects the lift of the sampling valve and generates voltage output. The schematic layout of the experimental setup is shown in Fig. 1.



Number	Device
1	Ricardo E6 Single Cylinder Research Engine
2	Electromagnetic Sampling Valve
3	Intake air conditioner
4	Flywheel
5	Dynamometer
6	Slit Disk/Photo Electric Reader
7	Cooling Water Tower + Water Pump + Heat Exchanger
8	2 x Oscilloscope
9	High-Speed Gas Sampling Device
10	Orifice and Air Tank
11	Inclined Manometer
12	Fuel Tank
13	Glass Measuring Tube
14	Ricardo E6 Engine Control Panel
15	Exhaust Silencer
16	Exhaust Gas Analyzer
17	Gas Chromatography Equipment + Data Logger + Gas Tubes

Fig. 1. Schematic layout of the experimental installation.

In-cylinder gas samples collected by an electromagnetic sampling valve located at opposite of the spark plug. The sampling unit is a Sokken model GSD-10 type unit. Inside the valve, on the valve rod one side it has electromagnet part, on the other side valve rod is mounted in to the seat of valve body using spring. When the electromagnet is triggered, it pulls the needle from the seat so that sampling gas flow through the valve into the sampling line. Sampling start and duration of valve is controlled by a pulse generator. Shorten the sampling duration time increases the resolution of the species evolution measurement. The sampling unit's minimum sampling time is 3 ms. However, at 1200 rpm engine speed the sampling time is 2.08 ms or 15 CA. This is obtained by adjusting the spring force using control panel. The opening duration is monitored using a LED (Light Emitting Diode) source and receiver pair. When the valve is triggered the needle lifts breaking the LED beam. The voltage from the LED receiver is monitored on an oscilloscope. Gas composition is obtained via a fast sampling



The variation of total amount of HC components, which include one to five carbon atoms per molecule (from CH<sub>4</sub> to C<sub>5</sub>H<sub>12</sub>), with respect to crank angle is given in Fig. 6.

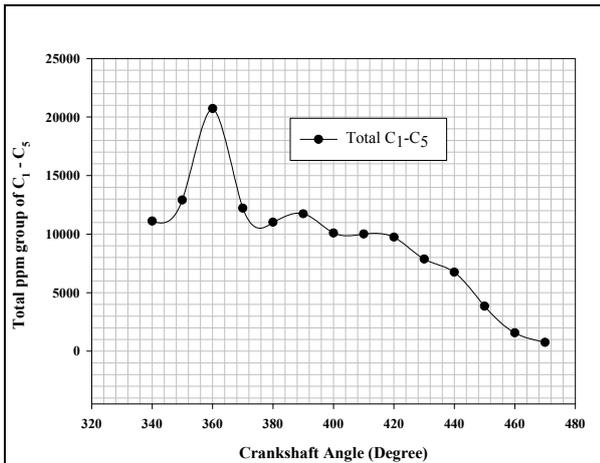


Fig. 6. Total amount of group of C<sub>1</sub>-C<sub>5</sub> HCs with respect to CA at r = 7:1 and N = 900 rpm.

When the spark ignition is occurred, HC level increases suddenly. This is an expectable result due to chemical degradation. At the end of the flame period, total C<sub>1</sub>-C<sub>5</sub> HC components decrease to 120 ppm level. This result is consistent with the total amount tailpipe exhaust gas HC emissions, when the engine is operated at the same conditions.

#### IV. CONCLUSIONS

Instantaneous HC component concentrations were analyzed simultaneously by using GC-FID technology. It is seen that the heavy HC components (as iso-pentane) tend to decrease during the flame period. On the other hand, light HC components (as ethylene, methane and acetylene) tend to rise during the expansion stroke. In addition, there is a peak value at the end of the combustion. This expected result shows that the chemical degradation occurs between the HC components during the combustion in the engine cylinder. This result should be taken into account for modeling of in-cylinder emission formation using CFD.

#### REFERENCES

- [1] N. Ladommatos, "Cyclically resolved measurements of hydrocarbons in the cylinders on internal combustion engines, by means of a fast flame ionization detector," *Journal of the Institute of Energy*, vol. 65 (463), pp. 94-101, 1992.
- [2] I. Shizuo and L. Tamotsu, "Experimental study on behavior of unburned hydrocarbons on combustion chamber wall of spark ignition engine," *Transactions of Japan Society of Mechanical Engineers*, vol. Part B 62 (596), pp. 1651-1658, 1996.
- [3] A.C. Alkidas, "Combustion chamber crevices: the major source of engine out hydrocarbon emissions under fully warmed conditions," *Progress in Energy and Combustion Science*, vol. 25, pp. 253-273, 1999.
- [4] H. Zuohua, Z. Ke, J. Deming, Z. Longbao, and P. Keyu, "Effect of fuel composition on hydrocarbon emissions in spark ignition engine," *Journal of Combustion Science and Technology*, vol. 3, no. 3, pp. 327-333, 1997.
- [5] N. A. Henein, and M. K. Tagomori, "Cold start hydrocarbon emissions in port-injected gasoline engines," *Progress in Energy and Combustion Science*, vol. 25, pp. 563-593, 1999.
- [6] N. Hadjconstantinou, K. Min, and J. B. Heywood, "Relation between flame propagation characteristics and hydrocarbon emissions under lean operating conditions in spark-ignition engines," in *Symposium on Combustion 2*, pp. 2637-2644, 1996.
- [7] B. M. Broderick and I. S. Marnane, "A comparison of the C<sub>2</sub>-C<sub>9</sub> hydrocarbon compositions of vehicle fuels and urban air in Dublin, Ireland," *Atmospheric Environment*, vol. 36, pp. 975-986, 2002.
- [8] C. S. McEnally, D. M. Ciparu, and L. D. Pfeifferle, "Experimental study fuel decomposition and hydrocarbon growth processes for practical fuel components: heptanes," *Combustion and Flame*, vol. 134, pp. 339-353, 2003.
- [9] W. Yang, "The Chemistry Controlling Post Combustion Hydrocarbon Oxidation and Homogeneous Charge Compression Ignition," Ph.D. dissertation, Dept. Mechanical Eng., Drexel University, 2002.



**Nuri Yuçel** was graduated from Istanbul Technical University, Mechanical Engineering Department in 1979, in Turkey. After graduation he worked as a maintenance engineer in Turkish Petroleum Corporation for 2 and half year. He received his M.Sc. degree from Polytechnic Institute of New York in U.S.A, in 1984, and Ph.D. degree in Polytechnic University of New York in U.S.A, in 1988. Yuçel is a member of Turkish Chamber of Mechanical Engineers and Turkish Society for Thermal Science and Technology. He is the editor-in-chief of *Journal of Thermal Science and Technology*. His major interest of study is numerical and experimental heat transfer, fluid flow, energy systems and internal combustion engines.

He worked as an assistant professor between 1988 and 1991 at Anadolu University in Eskisehir, Turkey. Later, he joined in Gazi University. He has been working as a full professor since 2000. He has many conference and journal papers.