CHAPTER IV

RESULTS AND DISCUSSION

Three blended fuels were used in the test : 1) base fuel without additives, 2) base fuel with tetrabutyltin, MTBE and IPA as additives, and 3)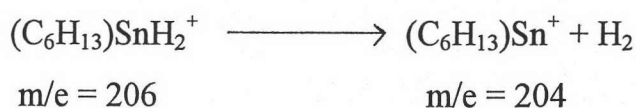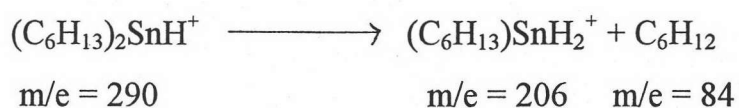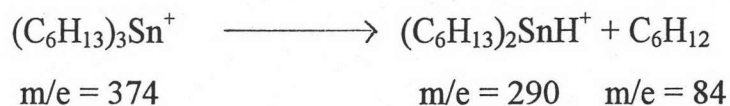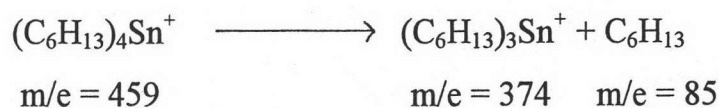 base fuel with tetrahexyltin which was synthesized by Grinard reaction, MTBE, and IPA as additives. Table 3.2 shows the compositions of these fuels. The properties of these blended fuels were tested according to ASTM standard method for testing properties of fuel and the results compared with those obtained from industrial standard means. Their octane numbers were also measured and compared to those of commercial gasolines. the blended Fuel1 was chosen to find the suitable condition of engine operation and investigation of exhaust emission. Spark timings and speed of the engine were varied. The exhaust emissions were analyzed and compared with those of commercial gasoline samples. Finally, various kinds of fuels, three blended fuels and·six other commercial fuels, were used to run the engine and the exhaust emissions obtained were analyzed. Results, such as properties of blended fuels , effect of spark timings and speeds of the engine, and effect of kinds of fuel used, on the exhaust emissions are reported and discussed here.

Synthesis of Tetrahexyltin

Tetrahexyltin was synthesized by Grignard reaction. Although the Grignard synthesis, consisting of many steps, required careful operation and the reactants were more expensive than the direct synthesis, however, the Grignard

synthesis had good selectivity and provides higher yield. In this study, the reaction gave 85.87% yield based on stannic chloride.

Characterization of the product with FTIR spectroscopy shown the characteristic peak of general alkyl group at 2957, 2953, 2852 cm^{-1}, etc., but the product couldn't be pointed out that was tetrahexyltin.

Characteristics of tetrahexyltin could be confirmed by using ^{13}C NMR and Mass spectrometer. ^{13}C NMR shown the peak of CH_3- at 14.19 ppm and -CH_2- at 22.86 , 27.14 , 31.59 , 34.14 ppm respectively. The peak of CH_2-Sn appeared at 9.263 ppm.

Mass spectrum shown base peak at 375 and the other peak at 291, 207, 123 due to the lost of C_6H_{12} group as the following mechanism.

and other equations that could be occurred such as :

$$(C_6H_{13})_4Sn^+ \longrightarrow (C_6H_{13})_3Sn^+ + C_6H_{13}$$

$$m/e = 459 \qquad\qquad m/e = 374 \quad m/e = 85$$

$$(C_6H_{13})_3Sn^+ \longrightarrow (C_6H_{13})_2SnH^+ + C_6H_{12}$$

$$m/e = 374 \qquad\qquad m/e = 290 \quad m/e = 84$$

$$(C_6H_{13})_2SnH^+ \longrightarrow (C_6H_{13})SnH_2^+ + C_6H_{12}$$

$$m/e = 290 \qquad\qquad m/e = 206 \quad m/e = 84$$

$$(C_6H_{13})SnH_2^+ \longrightarrow (C_6H_{13})Sn^+ + H_2$$

$$m/e = 206 \qquad\qquad m/e = 204$$

$$(C_6H_{13})_3Sn^+ \longrightarrow (C_6H_{13})_2Sn^+ + C_6H_{13}$$

$$m/e = 374 \qquad\qquad m/e = 289 \quad m/e = 85$$

$$(C_6H_{13})_2Sn^+ \longrightarrow (C_6H_{13})Sn^+ \longrightarrow SnH^+$$

$$m/e = 289 \qquad\qquad m/e = 204 \qquad m/e = 120$$

etc.
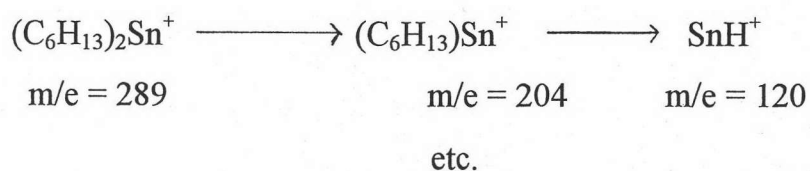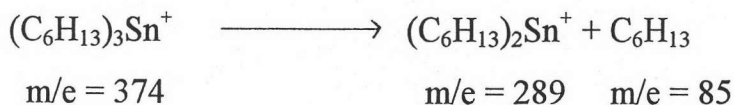
Test Properties of Blended Fuels

Base fuel, Fuel1, and Fuel2 were tested to determine their properties according to ASTM methods and the results obtained are shown in the Table 4.1.

Table 4.1 Properties of blended fuels

Properties	Specification		Base fuel	Fuel1	Fuel2
	Minimum	Maximum			
Gravity,°API	-	-	55.3	55.9	56.0
Specific gravity	-	-	0.7575	0.7556	0.7544
Density,g/ml	-	-	0.7572	0.7553	0.7541
Distillation, °C					
IBP	-	-	40.4	38.9	38.0
10%	-	70	58.2	55.2	55.0
50%	70	110	91.6	86.0	85.6
90%	-	170	140.6	138.7	138.4
FBP	-	200	170.0	170.0	170.0
Ried Vapor Pressure, KPa	-	62	49.6	51.7	51.0
Hydrocarbon type, %vol. Aromatic	–	50	43.2	42.2	42.2
Benzene content, %vol	–	3.5	4.0	3.7	3.7

Table 4.1 indicates that the properties of the blended fuels with in the specification of gasoline fuel. The octane numbers of the blended fuels and commercial gasolines are shown in the Table 4.2.

Table 4.2 Octane number of blended fuels and

commercial gasolines

Fuel	Octane number
Base fuel	89.0
Fuel1	92.0
Fuel2	91.2
CG1	92
CG2	92
CG3	97
CG4	97
CG5	97
CG6	97

Note :- CG1-CG2 = Unleaded regular commercial gasoline

CG3-CG6 = Unleaded premium commercial gasoline

Table 4.2 indicates that the octane numbers of Fuel1 and Fuel2 are similar to each other, 92 and 91.2 respectively, and both of them are higher than base fuel. The comparison of Fuel1 and Fuel2 with commercial gasolines, it is clear that the octane numbers of the blended fuels are similar to those of unleaded regular commercial gasolines.

Effect of Engine Parameters

The two parameters effecting the engine performance are spark timing and speed. In this study, Fuel1 was chosen to investigate these two parameters.

1. Effect of Spark Timing

In studying of effect of spark timing on exhaust emissions, engine speeds was fixed at 800 rpm and spark timing was varied to be 7, 10, 14, and 18.5 °BTDC. The amount of CO and HC in the exhaust gas was analyzed. The results obtained are shown in Table 4.3.

Table 4.3 Carbon monoxide and hydrocarbons in exhaust gases
at 800 rpm and various spark timing advances

Timing (°BTDC)	CO (%vol.)	HC (ppm.)
7	0.25	218.3
10	1.24	317.4
14	1.30	480.8
18.5	1.57	565.0

The data in Table 4.3 are plotted to show the relationship between spark timing and % volume of CO and the relationship between spark timing and concentration of hydrocarbon (ppm) in Figure 4.1 and Figure 4.2, respectively.

Figure 4.1 indicates that the % volume of CO at the spark timing 7°BTDC was rather low, 0.25 % volume, after that, it sharply increased with increased advance of the spark timing. Figure 4.2 shows a similar trend. This mean that concentration of hydrocarbon (ppm) is also sharply increased with increasing advance of the spark timing, as well.
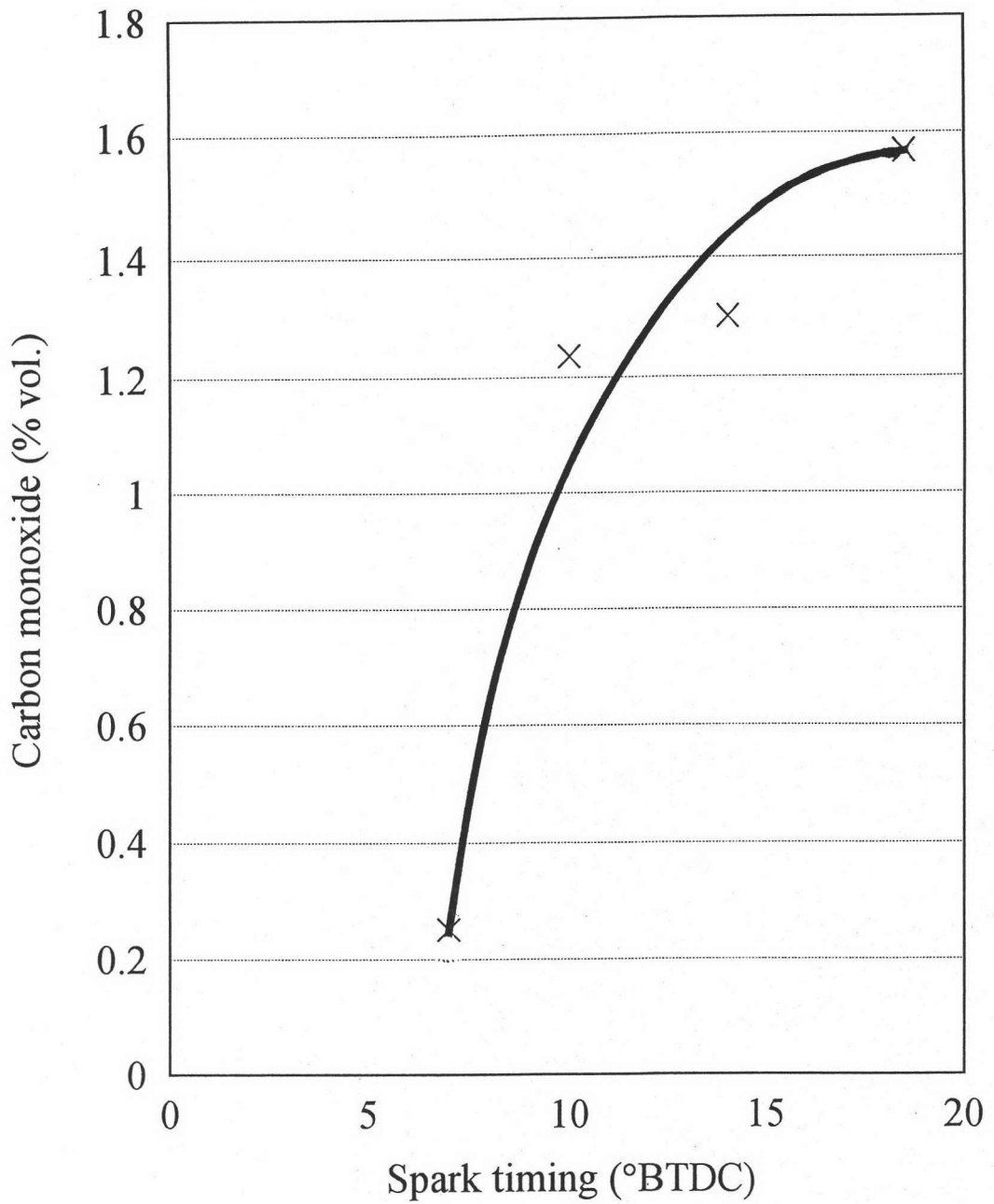
Figure 4.1 Effect of spark timing on carbon monoxide concentration in exhaust emissions
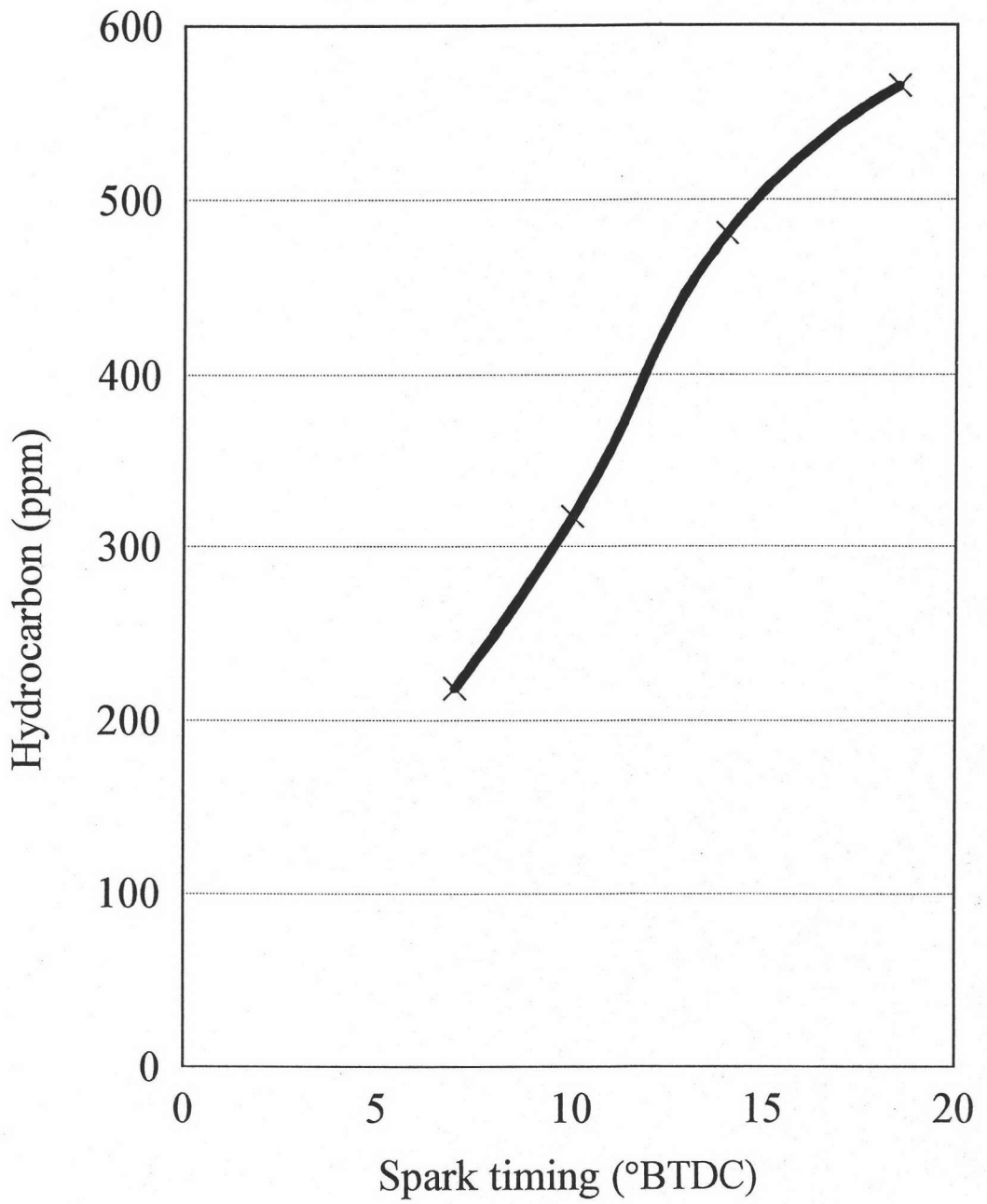
Figure 4.2 Effect of spark timing on hydrocarbon concentration in exhaust emissions

Figures 4.1 and 4.2 show that the more spark timing was retard, the lower the emission. The effect of spark timing retardation on HC emission reduction arises primarily from an increase in exhaust temperature, which promotes CO and HC oxidation and decreased in surface to volume ratio during combustion, emitted HC. Spark timing retardation has little effect on CO concentration expect at very retarded timing where the look of timing to complete CO oxidation leaded to increase CO emission.

Spark timing at 7 °BTDC should be appropriate to carry out on the next experiment because it could be observed that the contents of CO and HC are best at this timing.

2. Effect of Engine Speed

In the study of the effect of engine speed on exhaust emissions, engine spark timing was fixed at 7 °BTDC and engine speeds was varied to be 800, 1000, 1500, 2000, and 2500 rpm. The volume% of CO and concentrations of HC were measured and recorded in Table 4.4 as follows ;

**Table 4.4 Carbon monoxide and hydrocarbons in exhaust gases
at various operating speeds**

Speed (rpm)	CO (%vol.)	HC (ppm)
800	0.25	218.3
1000	0.16	149.3
1500	0.14	71.3
2000	0.14	60.9
2500	0.13	52.5

The data in Table 4.4 are plotted to show the relationship between engine speed and % volume CO and the relationship between engine speed and hydrocarbon concentration in Figure 4.3 and Figure 4.4, respectively.

It was found in Figure 4.3 that % volume of CO sharply decreases with increasing engine speeds in an exponential trend. The relationship between concentration of HC and engine speeds shown in Figure 4.4 is similar to that in Figure 4.3; that is the concentration of HC decreased with increasing engine speeds. Both % vol. of CO and concentration of HC, sharply decreased with modest engine speeds increase, for example, within the range of speeds 800-1500 rpm. As the speed continued to increase above 1500 rpm the concentrations did not change very much.

Figure 4.3 and Figure 4.4 show the effect of speed on exhaust emissions. Hydrocarbon concentration was remarkably reduced at higher engine speeds. At low rpm engine speed increases improve the combustion process within the cylinder by increasing turbulent mixing and Eddy diffusion. This promotes after-oxidation of the quenched layer. In addition, the increased exhaust port turbulence at higher speeds promotes exhaust system oxidation reaction through better mixing. Engine speed had little effect on CO emission because air-fuel ratio was changed by engine speed. At high speed, air-fuel ratio was lean then CO decreased. The test engine was run at the controlled speed of 800 rpm for testing the exhaust emissions of the various fuels because it was considered that this level of speed was similar to that of a car driven during a traffic-jam.
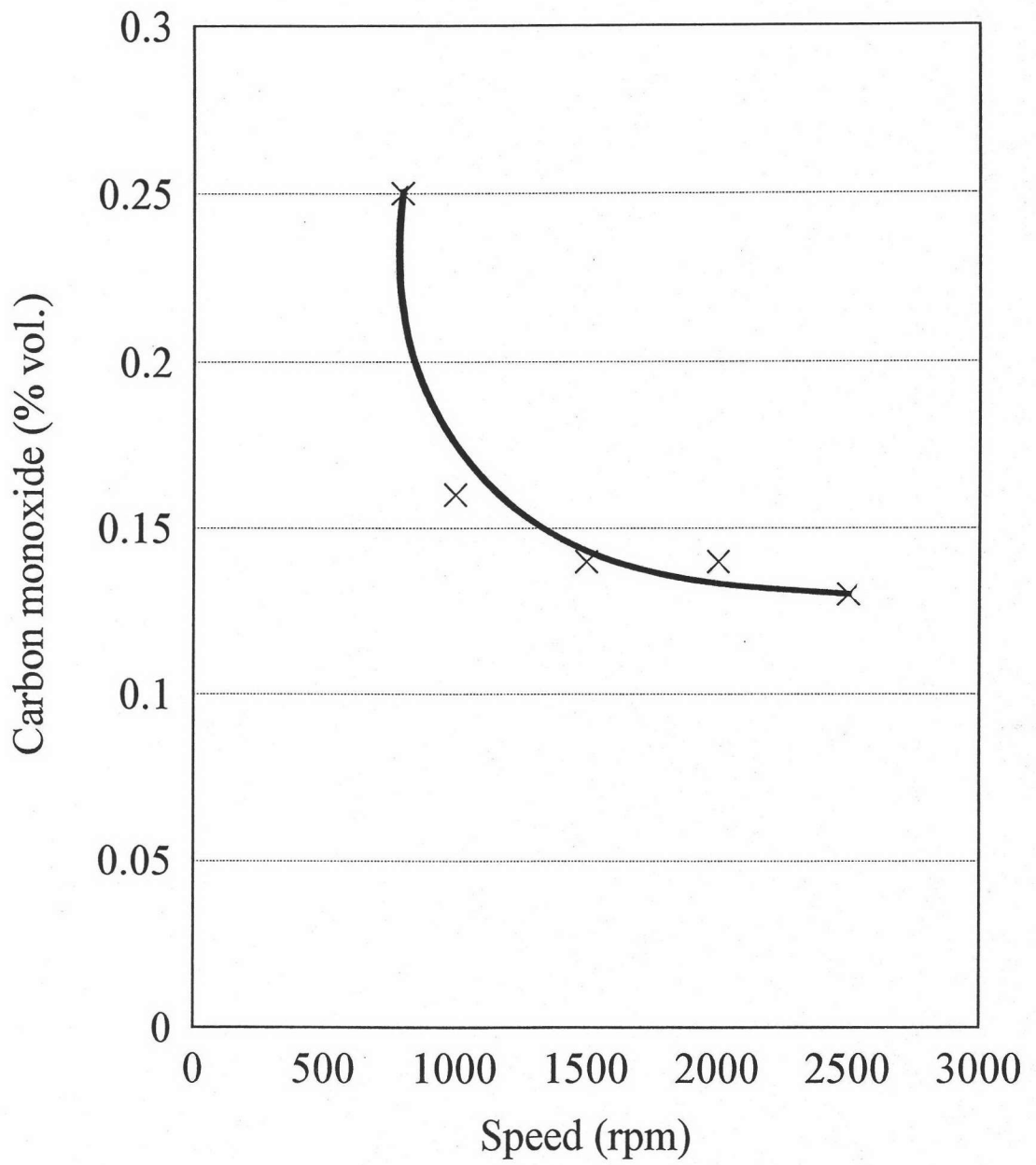
Figure 4.3 Effect of engine speed on carbon monoxide concentration in exhaust emissions
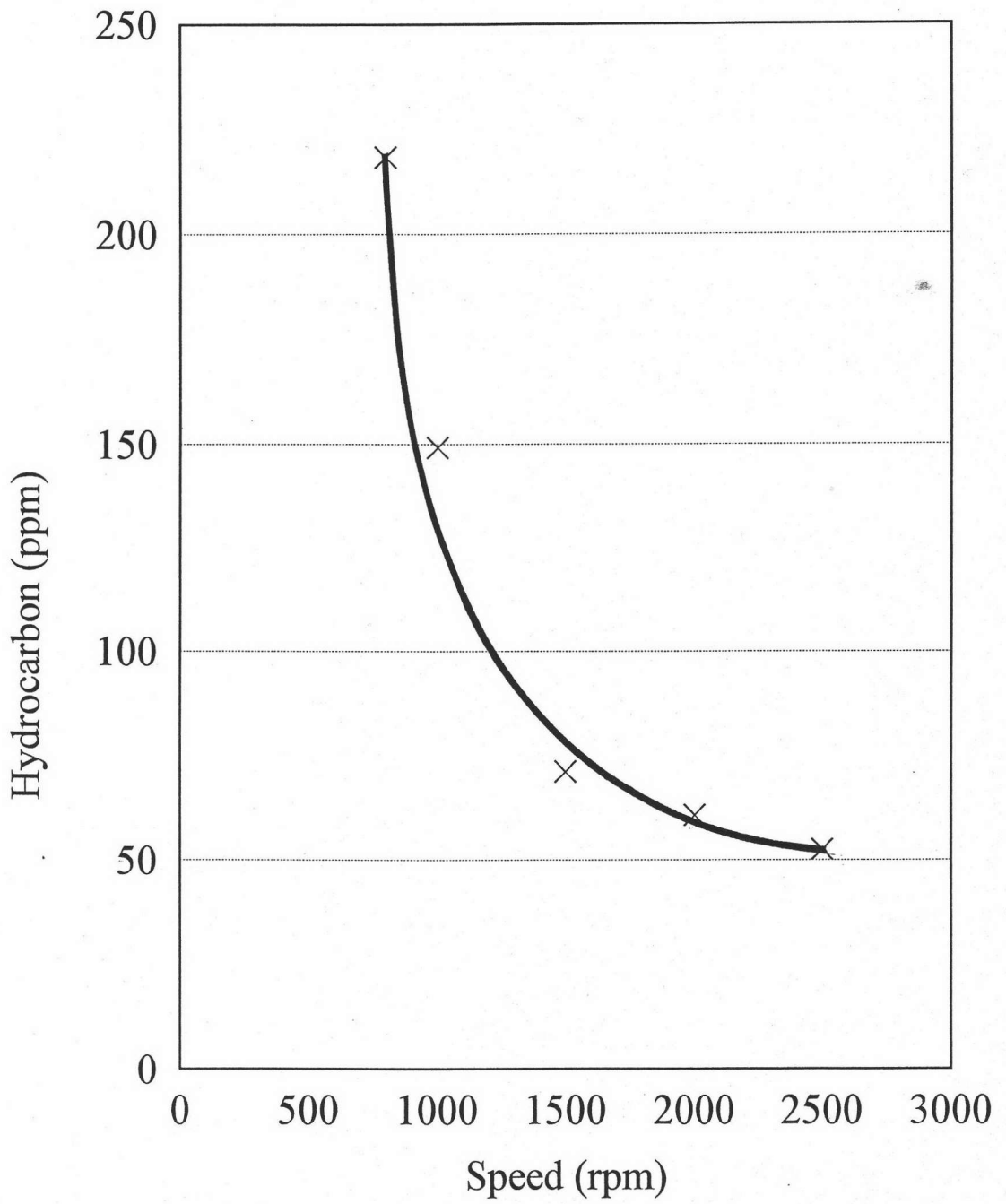
Figure 4.4 Effect of engine speed on hydrocarbon concentration in exhaust emissions

Effect of Fuel on Exhaust Emissions

The following tests were carried out for comparison of the exhaust emissions obtained from the blended fuels with those of commercial gasolines. Six commercial gasolines, namely CG1-CG6, were selected to use in the fuel tests. In these tests, the effect of the additives, as listed in Table 3.2 on exhaust emissions were studied in detail.

Carbon monoxide and hydrocarbon concentration of exhaust emission, by base fuel, Fuel1, Fuel2, and CG1-CG6 at spark timing 7 °BTDC and engine speed 800 rpm, are shown in Table 4.5

Table 4.5 Carbon monoxide and hydrocarbons in exhaust gases
at 800 rpm and 7 °BTDC

Fuel	CO (%vol.)	HC (ppm)
Base fuel	0.43	247
Fuel1	0.25	218
Fuel2	0.27	220
CG1	0.52	238
CG2	0.43	230
CG3	0.48	190
CG4	0.35	200
CG5	0.54	203
CG6	0.46	191

The relationships between fuels and % CO and fuels and hydrocarbon concentrations are shown in Figure 4.5 and Figure 4.6, respectively.

Histograms of Figure 4.5 show that carbon monoxide concentration of Fuel1 and Fuel2 are lower than base fuel because these oxygenated compounds will increase oxygen to the fuels (lean effect) and the final products obtained by the combustion of organotins, tin (IV) oxide (SnO_2) which give catalytic activities by changing CO to CO_2, therefore it is believed that it can decrease CO emission. Carbon monoxide concentration of Fuel1 is lower than Fuel2 because tetrabutyltin has high latent heat of vaporization, which decreases the intake manifold temperature and consequently increases the density of the air which has delivered to the combustion chamber (9). Carbon monoxide concentration of both Fuel1 and Fuel2 are lower than CG1-CG6. This indicates that the quality of the blended fuels are better than commercial gasoline samples.

Histograms in Figure 4.6 show that hydrocarbon emission of Fuel1 and Fuel2 are lower than base fuel because of lean effect and tin (IV) oxide. Hydrocarbon emission of Fuel1 is lower than Fuel2 about 2 ppm, which it is not significant. Hydrocarbon emissions of Fuel1 and Fuel2 are higher than CG3-CG6 that are unleaded premium commercial gasolines (octane number = 97) but are lower than CG1-CG2 that are unleaded regular commercial gasolines (octane number = 92 which is nearly the same as Fuel1 and Fuel2). These results indicate that the quality of the blended fuels are better than CG1-CG2 which is the same octane number.

Although exhaust emissions of Fuel1 and Fuel2 are nearly the same, Fuel1 is slightly lower, so Fuel1 was chosen for studying the compositions and concentration of hydrocarbon emissions.
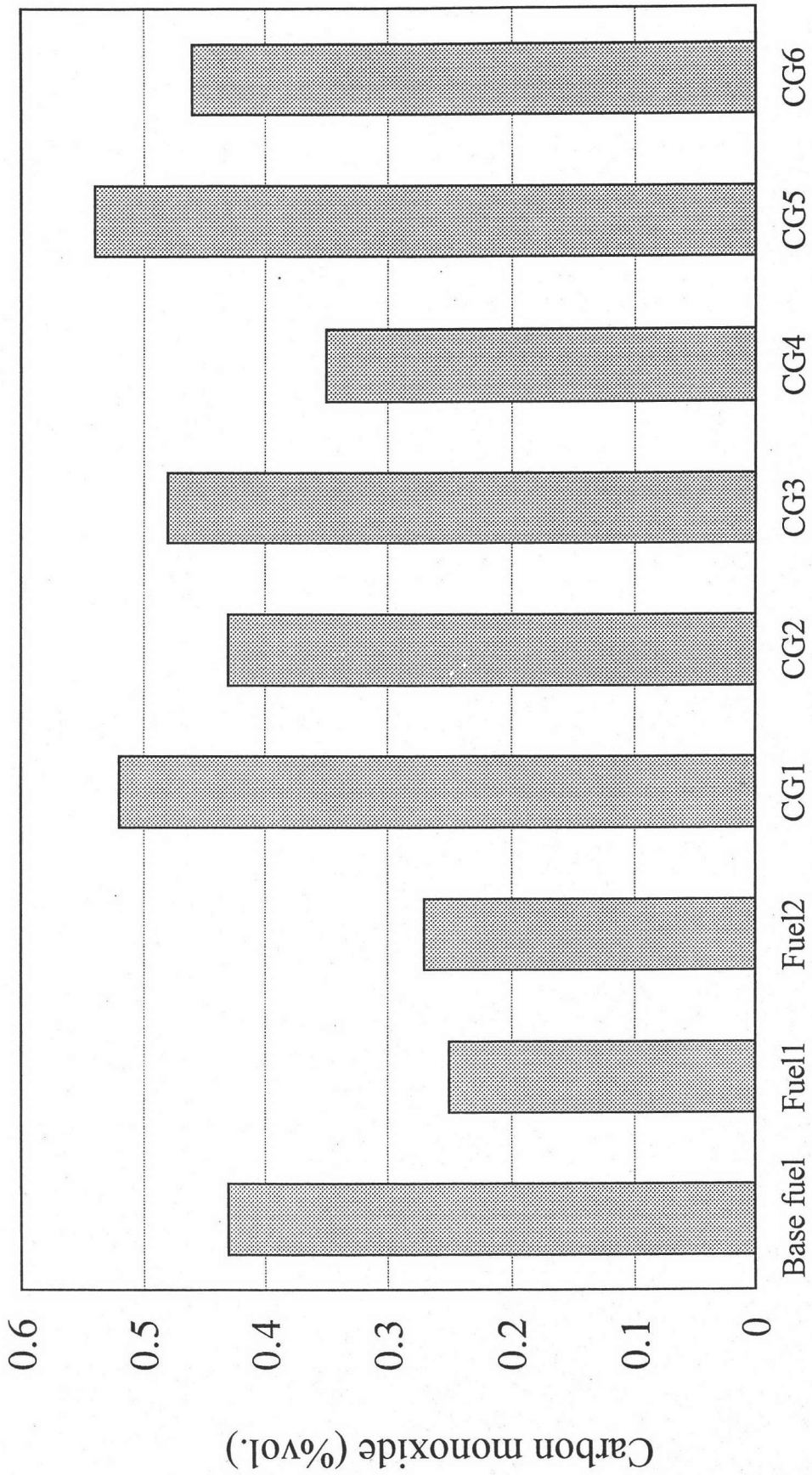
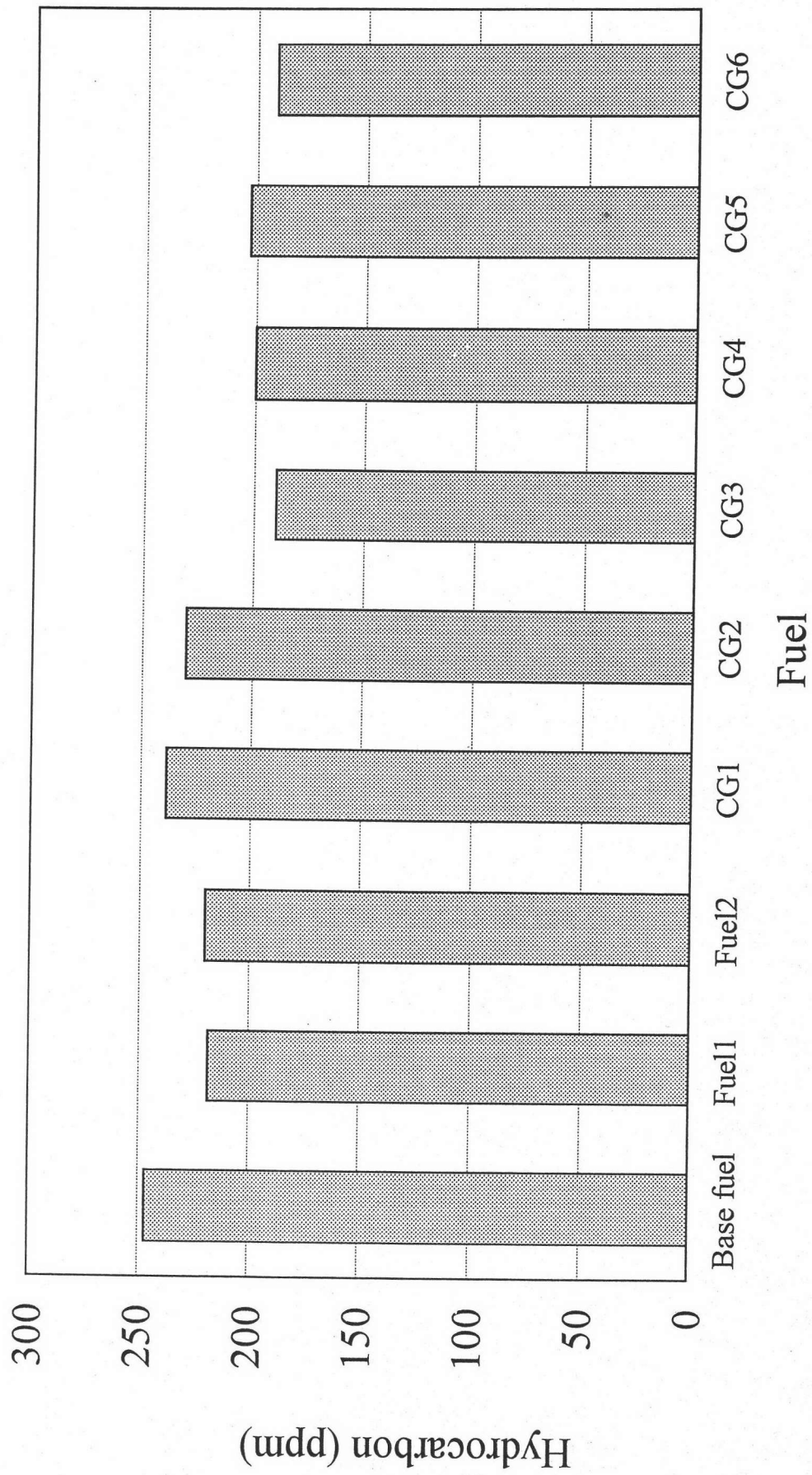**Figure 4.5 Effect of fuel composition on carbon monoxide concentration in exhaust gases at 800rpm and 7°BTDC**

Figure 4.6 Effect of fuel composition on hydrocarbon concentration in exhaust gases at 800rpm and 7°BTDC

Compositions and Concentrations of Hydrocarbons in Exhaust Gases of Fuel1

The composition of the hydrocarbon emission and the concentrations of individual components produced by the engine operated with Fuel1 at spark timing 7°BTDC and speed 800 and 1500 rpm are studied in detail. The results are shown in Table 4.6.The chromatogram is shown in Figure 4.7

Table 4.6 Compositions and concentrations of hydrocarbon emissions proceduced by Fuel1 at spark timing 7°BTDC and speeds of 800 and 1500 rpm

Emission	Composition number	Concentration (ppm)	
		800 rpm	**1500 rpm**
Isobutane	1	14.25	6.80
n-Butane	2	11.53	2.96
Isopentane	3	10.16	2.85
n-Pentane	4	10.16	2.08
2,2-Dimethylbutane	5	0.89	0.32
Cyclopentane	6	1.45	0.29
2-Methyl-pentane	7	5.91	ND
3-Methyl-pentane	8	3.54	0.19
Hexane	9	4.09	0.60
Methyl cyclopentane	10	4.10	0.33
Benzene	11	7.65	0.21
Toluene	12	15.10	0.19
m&p-Xylene	13	2.17	ND
o-Xylene	14	0.08	ND

Note :- **ND** = Non Detected

Chrom-Card

(mV)

40.689

32.557

24.426

16.294

8.163

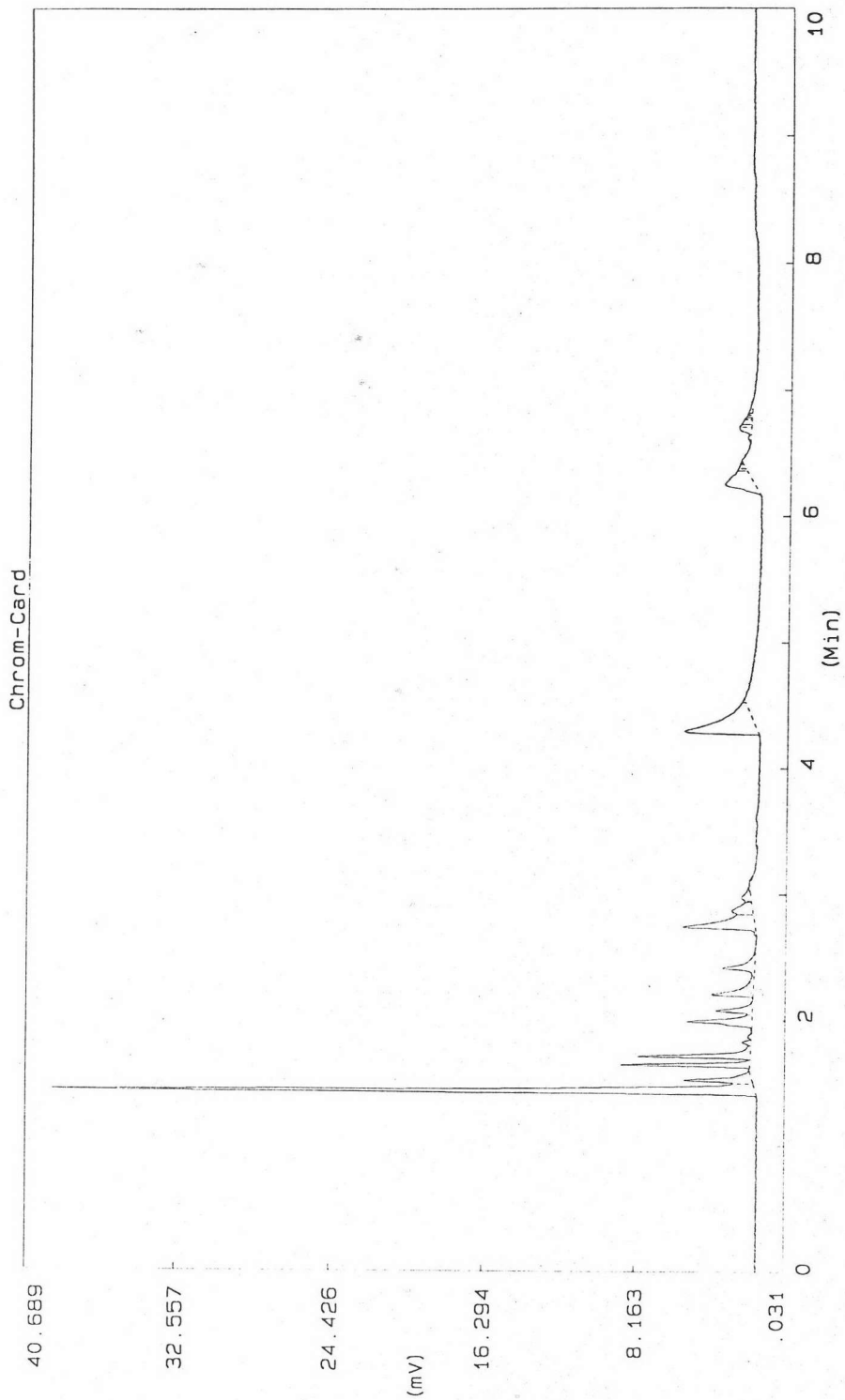.031

0 2 4 6 8 10

(Min)

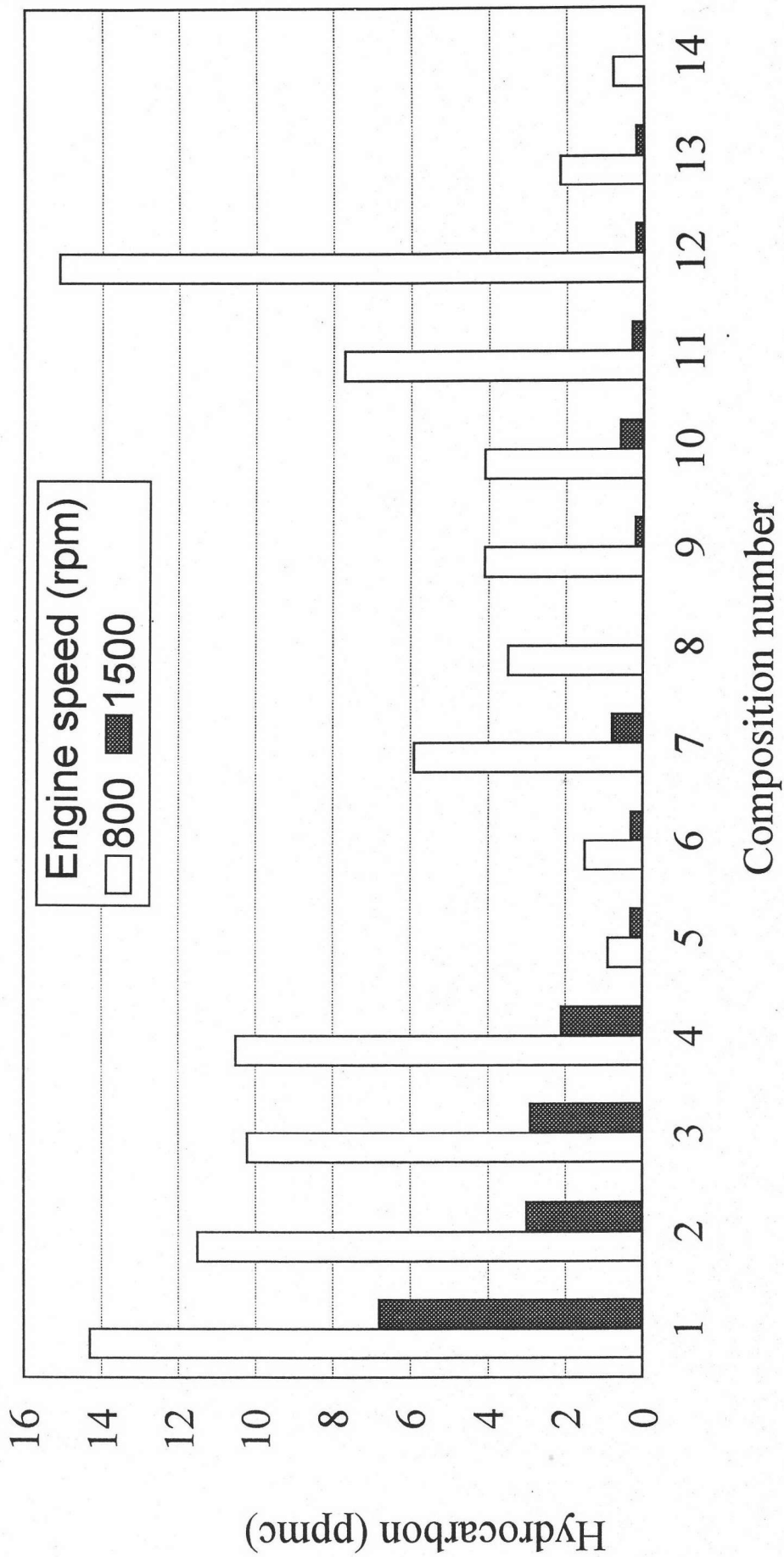**Figure 4.7 GC analysis of exhaust emissions sample from Fuel1**

Figure 4.8 Hydrocarbon emission concentrations in exhaust emissions from Fuel1 at 800 rpm and 1500 rpm

Relationships between compositions and concentration of hydrocarbon from Table 4.6 are plotted in Figure 4.8. It shows that at the speed of 800 rpm, the isobutane and toluene are higher than the other hydrocarbons. At speed of 1500 rpm, the exhaust emission of all hydrocarbons are decreased. Particularly, concentrations of benzene, toluene and xylene are very low. This indicates that the fuel undergoes more complete combustion at higher speed than at low speed.