CHAPTER IV

RESULT AND DISCUSSION

4.1 Identification of Fusel oil [10]

This research was aimed to investigate the effect of the addition of fusel oil into diesel oil, by measuring the amount of PAHs in the diesel exhaust. Crude fusel oil is a by-product of the fermentation of alcoholic beverages. It cannot be added directly into diesel oil because it is full of particles. Therefore, crude fusel oil has to be distilled before use.

Through normal atmospheric distillation, the crude fusel oil resulted in 87.82 % of fusel oil, and 12.18 % of black-brown residue. The fusel oil is an odorous transparent liquid. The fusel oil was characterized by GC-MS and found to consist of alcohols, and ether as shown in Table 4.1. The black-brown residue is a viscous liquid which is made up of aromatic compounds, carboxylic acids, and esters. The 13-NMR spectra of fusel oil and residue are shown in Appendix C

Table 4.1 The components of fusel oil obtained from normal atmospheric distillation.

Component	Yield(%V/V)
1,2,3-trimethyl cyclopentane (C_8H_{16})	12.33
2-methyl-2-penten-1-ol ($C_6H_{12}O$)	1.07
3-methyl-2-pentanol ($C_6H_{14}O$)	1.58
Hexyl methyl ether ($C_7H_{16}O$)	0.84
3-hexen-1-ol ($C_6H_{12}O$)	3.49
2,3-dimethyl-1-pentanol ($C_7H_{16}O$)	39.17
3-methyl-2-hexanol ($C_7H_{16}O$)	23.85
Others	18.74

4.2 Identification of PAHs[18]

PAHs in the diesel exhaust were identified and quantified by following the EPA 610 method using a GC technique The standard PAHs were used to establish a calibration curve for the quantitative analysis of each PAH.The analysis was carried out by comparing the peak area of each chromatogram to the calibration curve which is shown in Appendix A. The retention times, and detection limits of the individual PAHs are shown in Table 4.2; the percent recovery is shown in Table 4.4.

Table4.2 Molecular weight, retention time, and detection limit of standard PAHs

PAHs	MW	Retention time	Detection limit (ppm)
Naphthalene	128	6.99 ± 0.01	$1.336x10^{-3}$
Acenaphthylene	152	9.64 ± 0.01	nd
Acenaphthene	154	9.96 ± 0.01	$1.398x10^{-3}$
Fluorene	166	11.02 ± 0.01	$1.875x10^{-3}$
Phenanthrene	178	13.56 ± 0.01	$5.625x10^{-3}$
Anthracene	178	13.73 ± 0.01	$5.625x10^{-3}$
Fluoranthene	202	18.31 ± 0.01	$9.375x10^{-2}$
Pyrene	202	19.42 ± 0.01	$1.771x10^{-2}$
Benz[a]anthracene	228	26.74 ± 0.01	nd
Chrysene	228	26.97 ± 0.01	nd
Benzo[b]fluoranthene	252	34.00 ± 0.01	nd
Benzo[k]fluoranthene	252	34.18 ± 0.01	nd
Benzo[a]pyrene	252	36.05 ± 0.01	nd
Indeo[1,2,3-cd]pyrene	276	42.96 ± 0.01	nd
Dibenzo[a,k]anthracene	278	43.24 ± 0.01	nd
Benzo[ghi]perylene	276	44.41 ± 0.08	nd

nd : not determined

Table4.3 Comparison of the retention time of standard PAHs

PAHs	Retention time	
	Experimental	EPA(IP-7)[18]
Naphthalene	6.99 ± 0.01	7.10
Acenaphthylene	9.64 ± 0.01	10.24
Acenaphthene	9.96 ± 0.01	10.57
Fluorene	11.02 ± 0.01	11.56
Phenanthrene	13.56 ± 0.01	13.84
Anthracene	13.73 ± 0.01	14.04
Fluoranthene	18.31 ± 0.01	18.36
Pyrene	19.42 ± 0.01	19.37
Benz[a]anthracene	26.74 ± 0.01	26.42
Chrysene	26.97 ± 0.01	26.66
Benzo[b]fluoranthene	34.00 ± 0.01	33.55
Benzo[k]fluoranthene	34.18 ± 0.01	33.72
Benzo[a]pyrene	36.05 ± 0.01	35.53
Indeo[1,2,3-cd]pyrene	42.96 ± 0.01	42.34
Dibenzo[a,k]anthracene	43.24 ± 0.01	42.62
Benzo[ghi]perylene	44.41 ± 0.08	43.70

Table4.4 Percent recovery of standard PAHs

PAHs	% recovery
Naphthalene	80.15
Acenaphthylene	nd
Acenaphthene	84.05
Fluorene	87.44
Phenanthrene	88.19
Anthracene	88.40
Fluoranthene	89.18
Pyrene	89.71
Benz[a]anthracene	nd
Chrysene	nd
Benzo[b]fluoranthene	nd
Benzo[k]fluoranthene	nd
Benzo[a]pyrene	nd
Indeo[1,2,3-cd]pyrene	nd
Dibenzo[a,k]anthracene	nd
Benzo[ghi]perylene	nd

nd : not determined

4.3 Properties of Diesel Fuel

The pure, distilled diesel fuel was blended with 0, 2, 4, 6, 8, and 10% V/V of fusel oil. The properties of the blended fuel were tested according to the ASTM standard methods, and are shown in Table 4.5.

Table 4.5 Properties of base diesel oil and diesel oil blended with fusel oil

TEST ITEMS	ASTM	LIMITS	Fusel Oil Concentration (vol %)					
			0	2	4	6	8	10
API Gravity @ 60 °F	D 1298	Report	36.9	37.1	37.4	37.6	37.7	37.9
Specific Gravity @ 60/60	D 1298	0.81-0.87	0.840	0.839	0.838	0.837	0.836	0.835
Calculated Cetane Index	D 976	47 min	51.77	52.05	52.04	52.00	51.80	51.81
Flash Point, (P.M.), °C	D 93	52 min	68	44	40	40	39	38
Distillation °C	D 86							
IBP		report	175.9	138.9	116.4	94.6	94.2	93.3
10% recovered		report	203.2	199.8	191.6	178.4	167.1	151.1
50% recovered		report	273.3	273.0	270.4	268.4	266.8	265.3
90% recovered		357 max	346.0	347.3	346.2	345.0	345.3	345.1
Water Content (ppm)	D 2709	0.05 max	0.01	0.02	0.04	0.10	0.15	0.20

The results in Table 4.5 indicate that the flash point and distillation point decreased with the addition of fusel oil,while the API gravity and specific gravity slightly increased. However, in 1997, Tuntipisit[17] found that blending isoamyl alcohol into diesel oil yielded a flash point higher than that of the fusel oil used in this study. This flash point did not reach the standard limit value. If the flash point is too low (lower than the standard limit value), then there is a tendency for the static electricity to build up during use. This may result in discharge sparking and can cause an ignition, fire, or explosion. To solve this problem, diesel oil with a higher flash point should be blended into the fusel oil.

4.4 Effect of Engine Speed on PAHs

Engine speeds of 800, 1600, and 2400 rpm were selected for this research. The 800 rpm is the engine speed during traffic congestion while the 1600 and 2400 rpm are the engine speeds during medium and high running conditions, respectively. The amount of PAHs in the diesel exhaust is shown in Table 4.6. The engine speed of 800 rpm resulted in large amounts of PAHs; while that of 2400 rpm resulted in the lowest PAHs.

Table 4.6 The amount of PAHs in base diesel fuel exhaust at 800, 1600 and 2400 rpm of diesel engine.

PAHs	The amount of PAHs (ppm)		
	800 rpm	1600 rpm	2400 rpm
Naphthalene	8.35±(0.02)	7.08±(0.17)	7.12±(0.02)
Acenaphthylene	13.43±(0.08)	13.10±(0.16)	13.00±(0.04)
Acenaphthene	6.36±(0.01)	6.36±(0.02)	6.34±(0.02)
Fluorene	1.10±(0.02)	1.13±(0.04)	1.10±(0.04)
Phenanthrene	0.26±(0.01)	0.24±(0.01)	0.24±(0.01)
Anthracene	2.27±(0.12)	1.49±(0.30)	1.30±(0.27)
Fluoranthene	0.15±(0.01)	0.13±(0.01)	0.13±(0.01)
Pyrene	0.06±(0.01)	0.05±(0.01)	0.02±(0.01)
Benzo[b]fluoranthene	0.14±(0.01)	0.04±(0.01)	0.13±(0.02)
Total	**32.12 ±(0.18)**	**29.62 ±(0.67)**	**29.38 ±(0.31)**

The amount of PAHs decreases when the engine speed was varied from 800 rpm to 1600 rpm and 2400 rpm. At the engine speed of 800 rpm, the amount of PAHs is the highest emission because there is a low combustion chamber temperature which leads to low oxidation. At the engine speeds of 1600, and 2400 rpm, the amount of PAHs in the diesel exhaust is lower than 800 rpm because the combustion temperature is higher. These results indicate that at the lowest engine speed of 800 rpm, there is the highest emission of PAHs. Therefore, during traffic congestion, the greatest emissions of PAHs occur.

4.5 Effect of concentration of fusel oil on PAHs

The engine speed was fixed at 800, 1600 , and 2400 rpm and the fusel oil used varied from 0, 2, 4, 6, 8, and 10 % by volume. The amount of PAHs in the exhaust gas was analyzed by GC. The results are shown in Figures 4.1-4.9

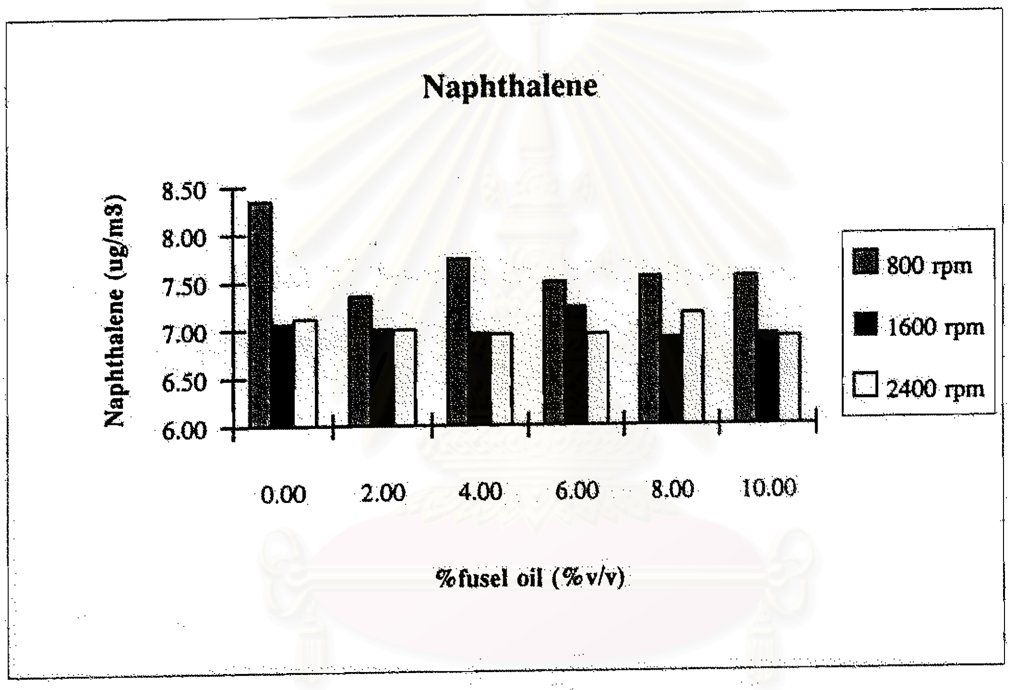

Figure 4.1 The effect of fusel oil on naphthalene in diesel exhaust at different engine speeds

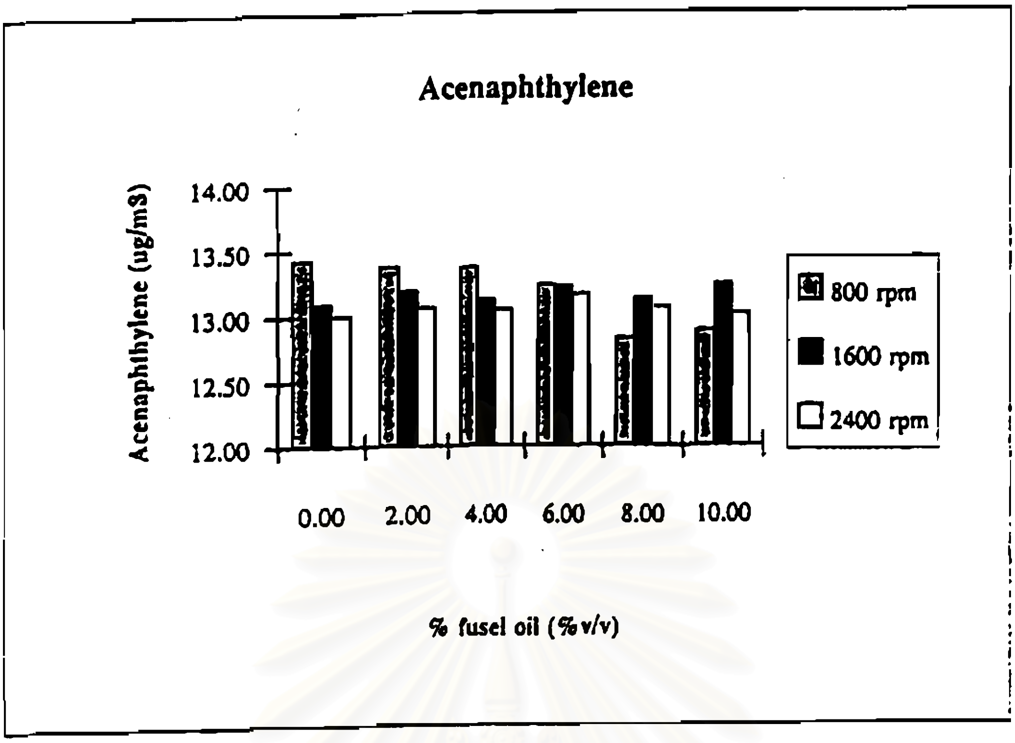

Figure 4.2 The effect of fusel oil on acenaphthylene in diesel exhaust at different engine speeds

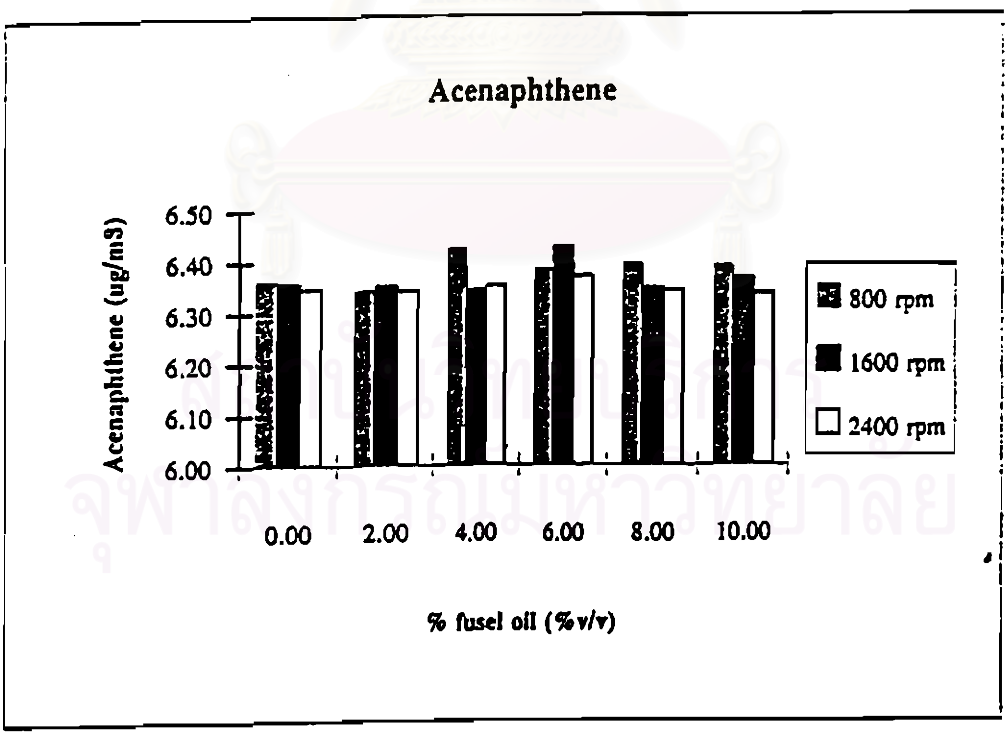

Figure 4.3 The effect of fusel oil on acenaphthene in diesel exhaust at different engine speeds

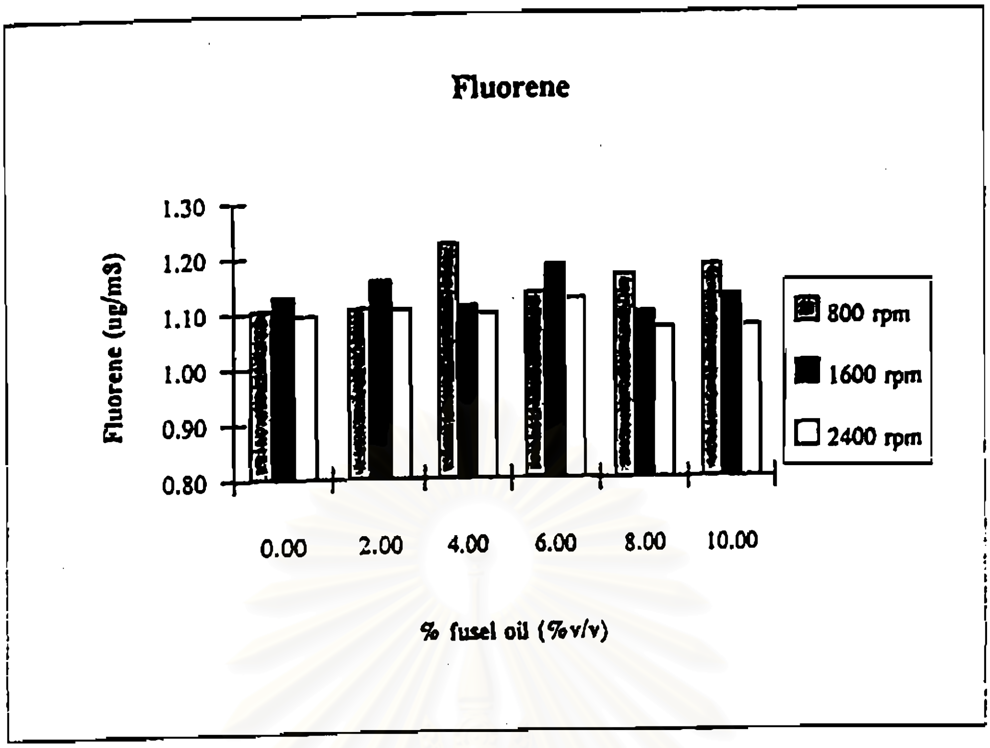

Figure 4.4 The effect of fusel oil on fluorene in diesel exhaust at different engine speeds

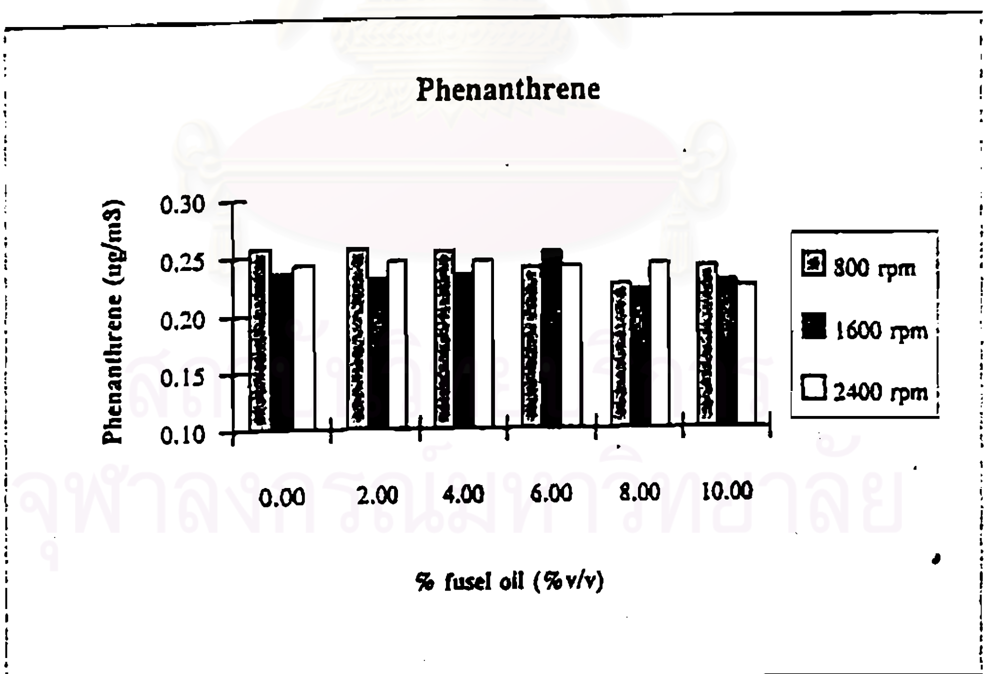

Figure 4.5 The effect of fusel oil on phenanthrene in diesel exhaust at different engine speeds

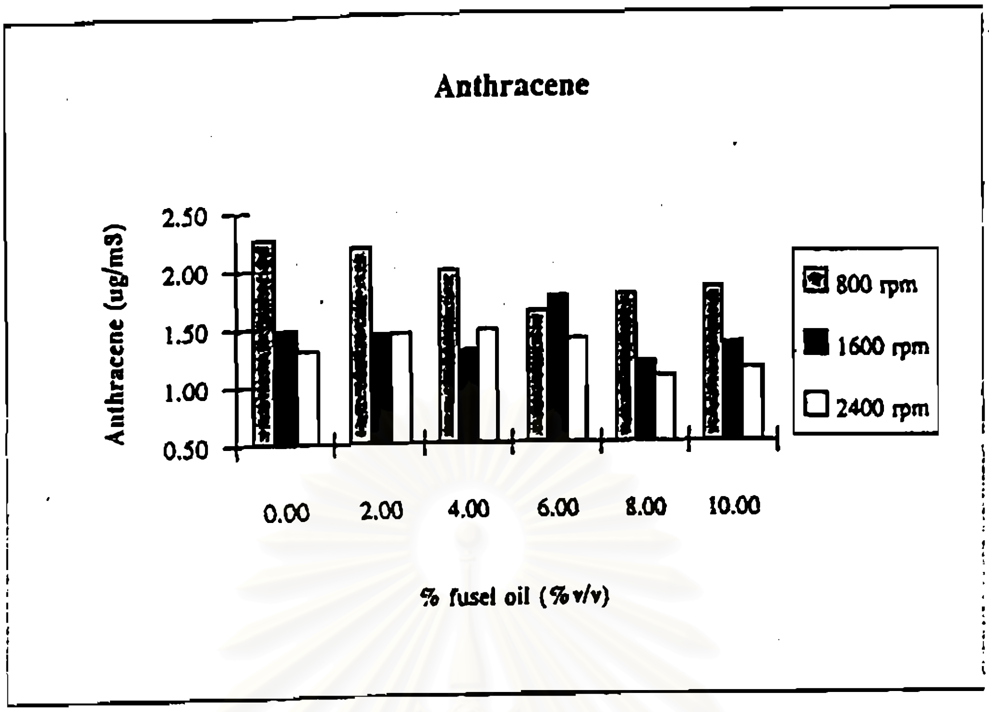

Figure 4.6 The effect of fusel oil on anthracene in diesel exhaust at different engine speeds

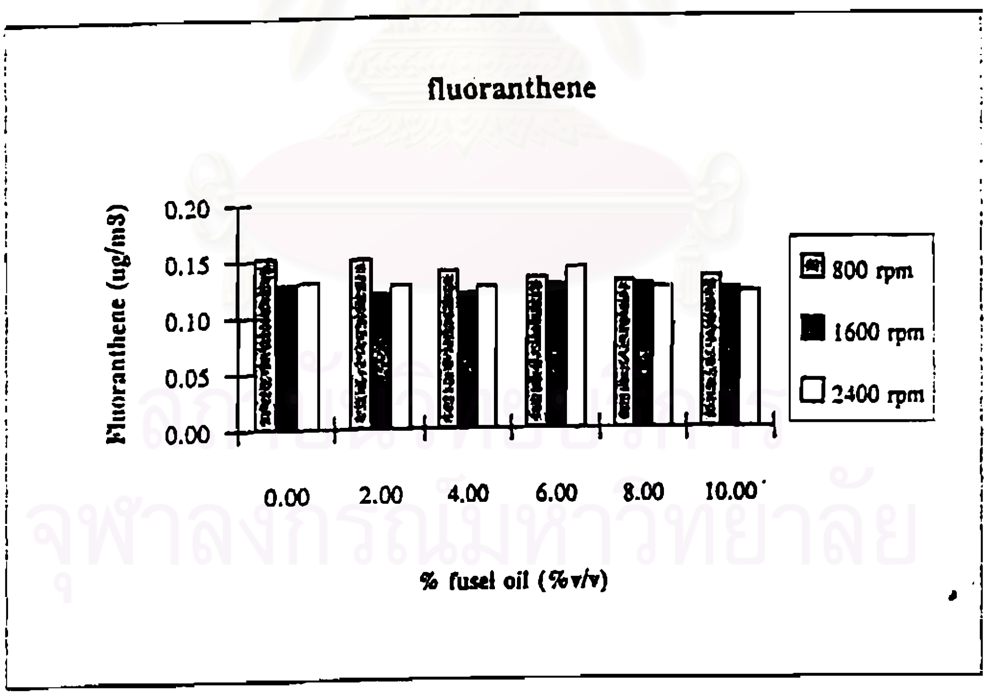

Figure 4.7 The effect of fusel oil on fluoranthene in diesel exhaust at different engine speeds

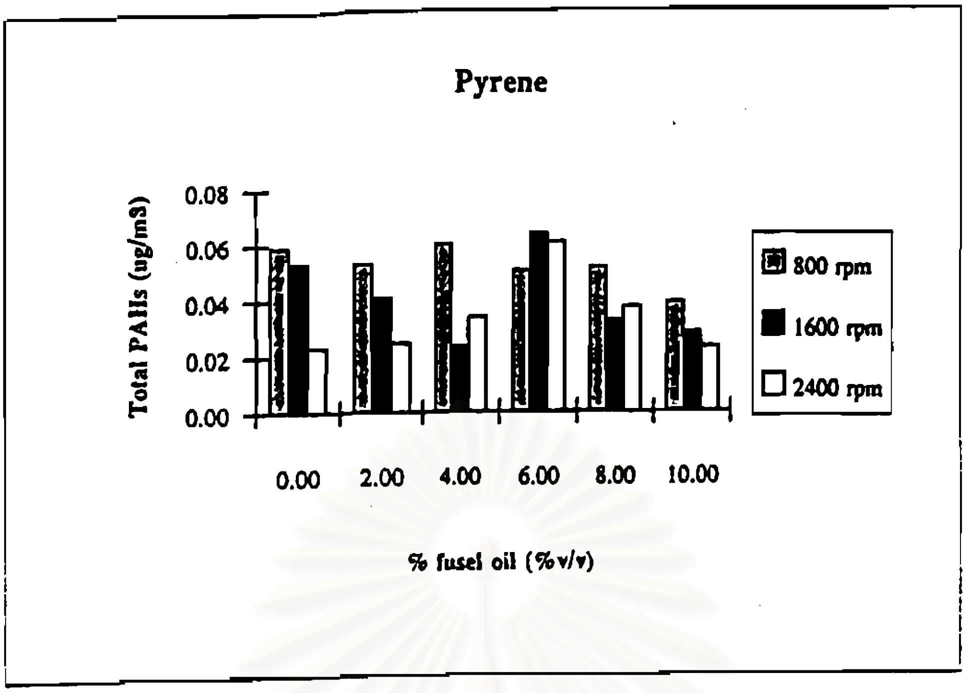

Figure 4.8 The effect of fusel oil on pyrene in diesel exhaust at different engine speeds

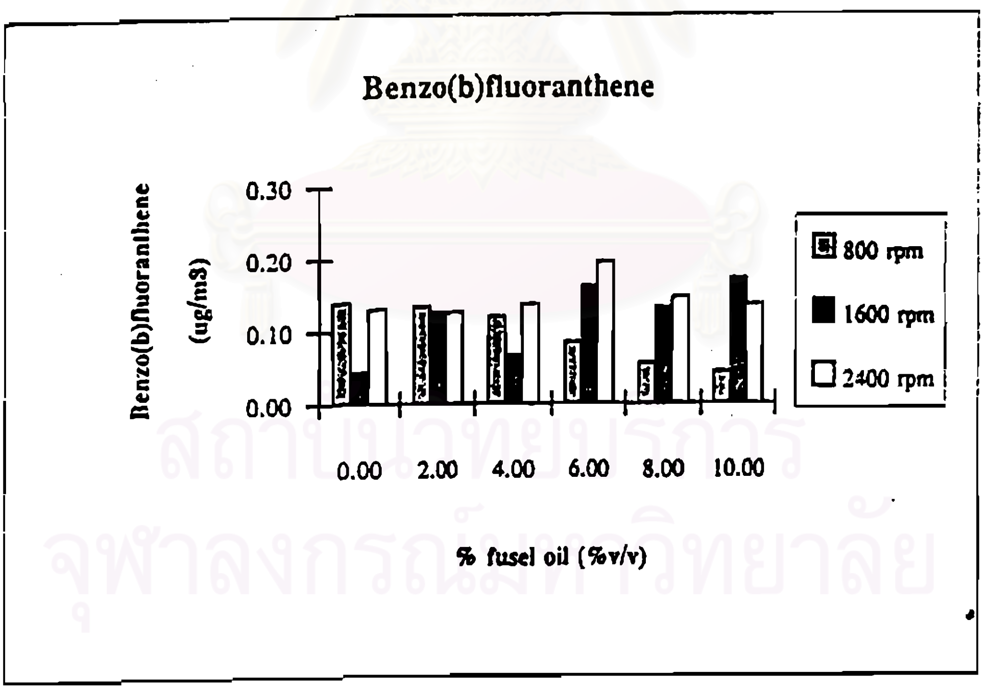

Figure 4.9 The effect of fusel oil on benzo(b)fluoranthene in diesel exhaust at different engine speeds

Figures 4.1-4.9 show that as a result of the addition of fusel oil into pure, distilled diesel fuel, the amount of PAHs in the diesel exhaust reduced. The amount of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, and benzo(b)fluoranthene decreased with increasing concentrations of fusel oil. Among these PAHs, naphthalene, acenapthylene, and acenaphthene are the main constituents Table 4.7 shows the amount of total PAHs in the diesel exhaust emission when the fusel oil was increased.

Table 4.7 Effect of concentration of fusel oil on total PAHs in exhaust emission at 800, 1600, and 2400 rpm of diesel engine.

Concentration of fusel oil (% vol)	The amount of total PAHs ($\mu g/m^3$)		
	800 rpm	1600 rpm	2400 rpm
0	32.12±(0.18)	29.62±(0.67)	29.38±(0.31)
2	31.00±(0.71)	29.69±(0.36)	29.49±(0.31)
4	31.32±(0.14)	29.29±(0.37)	29.46±(0.71)
6	30.39±(0.55)	30.46±(0.92)	29.63±(0.41)
8	30.18±(0.48)	29.20±(0.16)	29.48±(1.27)
10	30.29±(0.69)	29.59±(0.13)	28.96±(0.30)

The data in Table 4.7 was plotted to show the relationship between the concentration of fusel oil and engine speeds with the amount of total PAHs as shown in Figure 4.10.

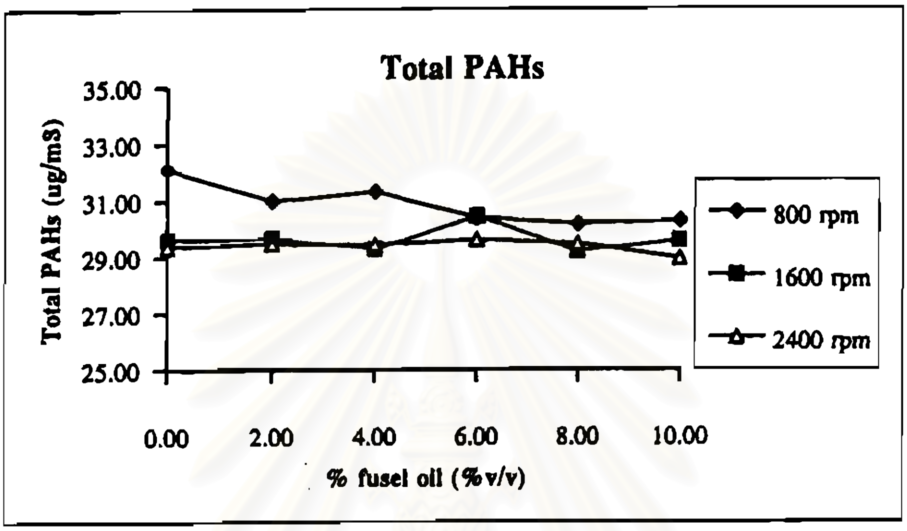

Figure 4.10 The effect of concentration of fusel oil on total PAHs in exhaust emission at different engine speeds.

The amount of PAHs decreased when the amount of fusel oil in blended fuel was increased from 0, 2, 4, 6, 8, and 10 % by volume, respectively. The pure, distilled diesel fuel generated the highest the amounts of PAHs. The blended fuel on the other hand, generated lower amounts of PAHs However, the amount of PAHs slightly decreased at the same engine speed. These results are similar to that of Tuntipisit[17]. In 1997, Tuntipisit found that as a result of the addition of isoamyl alcohol, the amount of PAHs decreased to less than 10 ppm. These amounts were lower than that of the fuel oil used in this study. In 1985, Sweeney[12] studied the effect of amyl alcohol on flash point of diesel oil. It was found that the distillation point and the flash point are decreased when the amyl alcohol was added into diesel oil. However, these results showed that the distillation and the flash point are lower than added fusel oil into diesel oil.

The results in Table 4.7 were statistically tested by testing the regression equation by SPSS for MS WINDOWS Release 6.0. All the regression equation testings are shown in Appendix D. We adjusted the amount of PAHs to be the dependent variable and the engine speed and the concentration of fusel oil to be independent variables. The results indicated that the data of all samplings were accepted because the significance-F was lower than the acceptable limit (0.05%). The significance-F of this research is 0.003%. The beta value shows that the engine speed is a more influential variable than the concentration of fusel oil. The amount of PAHs decreased when the engine speed and the concentration of fusel oil increased because the beta value was negative. The regression equation is:

$$Y = 31.814286 - 9.27083E\text{-}04X_{rpm} - 0.071190X_{fusel}$$

When

Y is the amount of PAHs

X_{rpm} is the engine speed

X_{fusel} is the concentration of fusel oil