CHAPTER 5

DISCUSSION

5.1 Total Identified VOCs (TVOC)

5.1.1 Spatial and Temporal Distribution of TVOC in Bangkok

The ambient VOC concentration in Bangkok was found to be different between the SW and NE monsoon seasons. At all 4 stations in Bangkok, the average TVOC concentrations during the SW monsoon season were higher than the concentrations during the NE monsoon season. This was likely to be caused by the difference in atmospheric conditions. During the SW monsoon, the prevalent weather conditions were of cloud and rain. In contrast, during the NE monsoon the weather conditions were clear with strong sunshine. The report on ozone episodes showed that these mostly occurred in the dry season, November to March (PCD, 2001). Ozone episodes were caused by strong sunshine promoting photochemical reactions leading to high ozone concentrations but resulting in a depletion of ozone precursor substances such as VOCs (Figure 5.1).

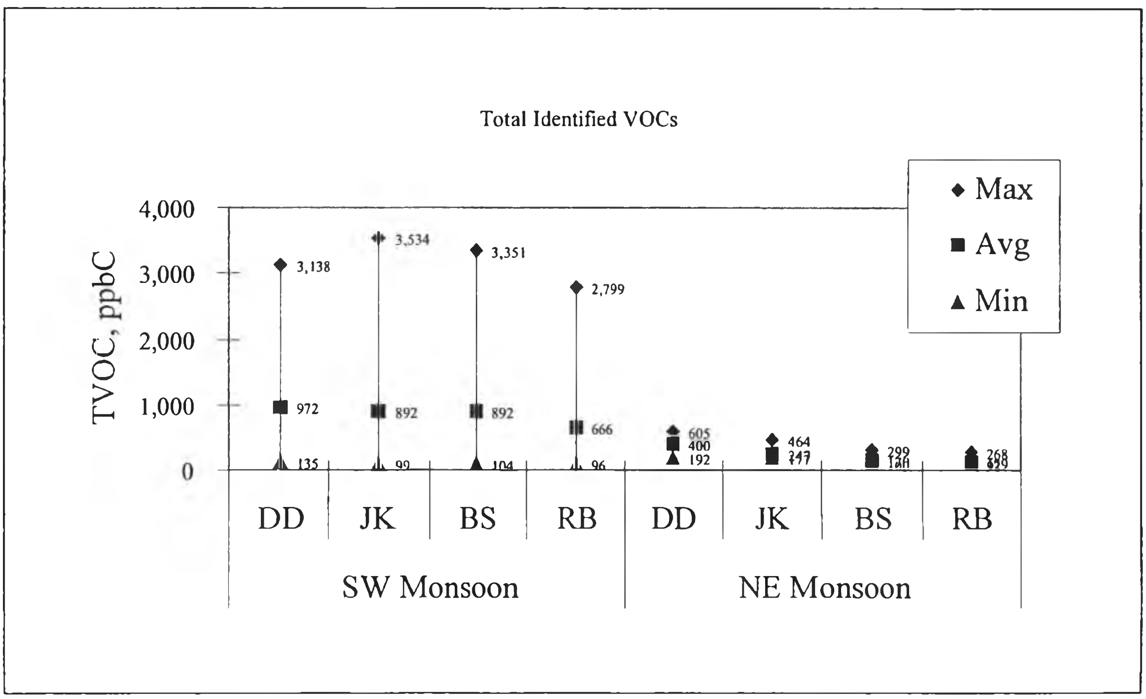

Figure 5.1 Spatial and Temporal Distribution of TVOC in Bangkok

TVOC concentrations at each station, during both the SW and NE monsoon seasons, showed the same pattern. DD station near the road had the highest average TVOC concentrations. JK and BS stations, a commercial and residential area north and south of Bangkok, had TVOC concentrations at similar levels. RB station, an industrial area had the lowest TVOC concentrations.

5.1.2 Comparison to Other Studies

In August 2002, Laowakul, et al. (2003) studied VOC concentrations in 4 areas at roadsides in Bangkok: Yaowarat, Silom, Victory Monument and Ratchayothin. That study found that TVOC in Bangkok had a range of between 1,036.5 - 5,379.1 $\mu g/m^3$ or 2,112 – 10,960 ppbC. This study found that near the road at DD station, the average TVOC were 400 - 973 ppbC. The commercial and residential areas, north and south of Bangkok: JK station, BS station and the industrial area south of Bangkok: RB station had average TVOC values at 235 - 892, 170 - 892, and 129 - 666 ppbC, respectively. Table 5.1 compares TVOC found in this study to that in the other studies.

Table 5.1 TVOC Concentrations in Bangkok and Other Cities

Unit: ppmC

Places	Background/Urban	Roadway/Roadside
Melbourne (1)	0.242 ± 0.158	0.980 ± 0.070
Hong Kong (1)	0.229 ± 0.058	0.616 ± 0.232
Bangkok, 2000 (1)	0.568 ± 0.230	4.176 ± 1.502
Bangkok, 2002 (2)	-	2.112-10.960
Bangkok, 2003-2004 (3)	**0.129-0.892**	**0.400-0.973**

Source: (1) Limpaseni, et al., 2003

(2) Laowakul, et al., 2003

(3) This study

5.1.3 Relationship of TVOC and Ozone Concentration

When comparing TVOC concentration sampling in the morning from this study to the maximum 1-hr ozone concentration from a PCD monitoring station on the same sampling days at DD station, the relationship between TVOC and ozone was found to be low, R^2 = 0.2 (Figure 5.2). However, the relationship confirms that the high ozone concentration was likely to result from the depletion of TVOC which were the precursors for ozone formation. Data at JK station were not available at the same period of sampling, since the monitoring station was in the process of being relocated. At BS and RB stations, there were no data on ozone.

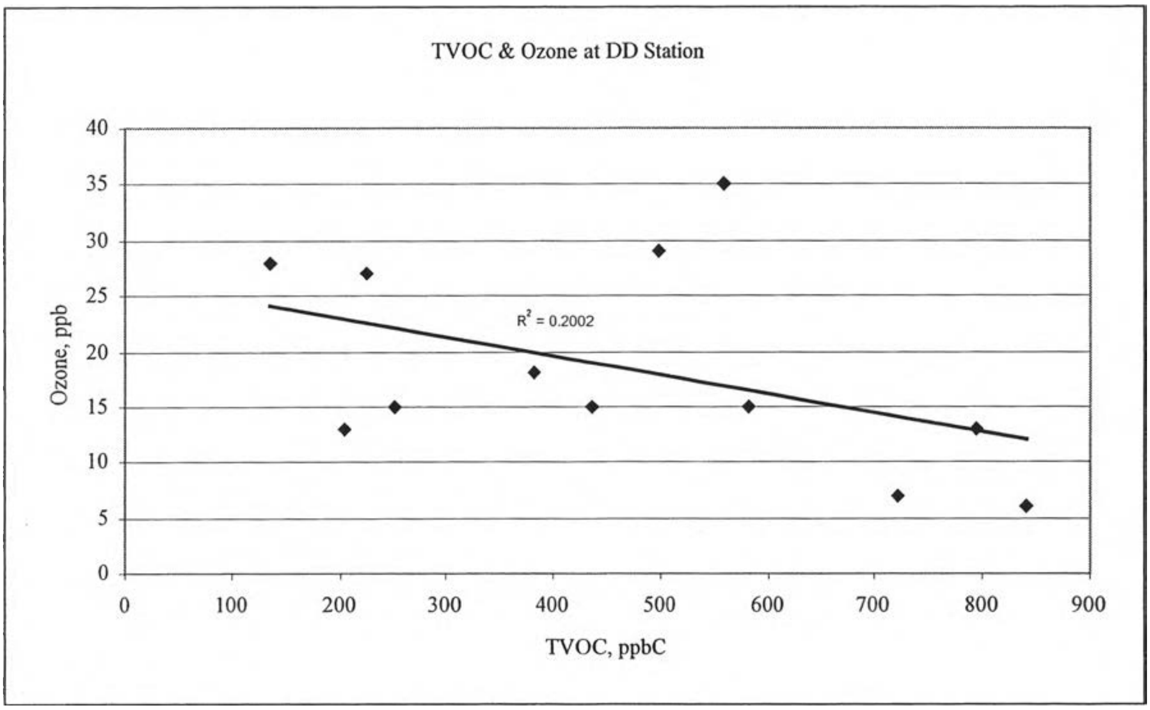

Figure 5.2 Relationship of TVOC and Ozone at DD Station

5.1.4 Relationship of TVOC and NMHC Concentration

When comparing TVOC concentration in this study to NMHC concentration from a PCD monitoring station in the same hour of sampling days at DD station, the relationship between TVOC and NMHC was strong with $R^2 = 0.7188$. The relationship shows that the high TVOC concentrations correspond with high NMHC concentrations. The measured TVOC in this study represents approximately 40% of NMHC in ambient air according to the derived relationship, Y = 0.4136X.

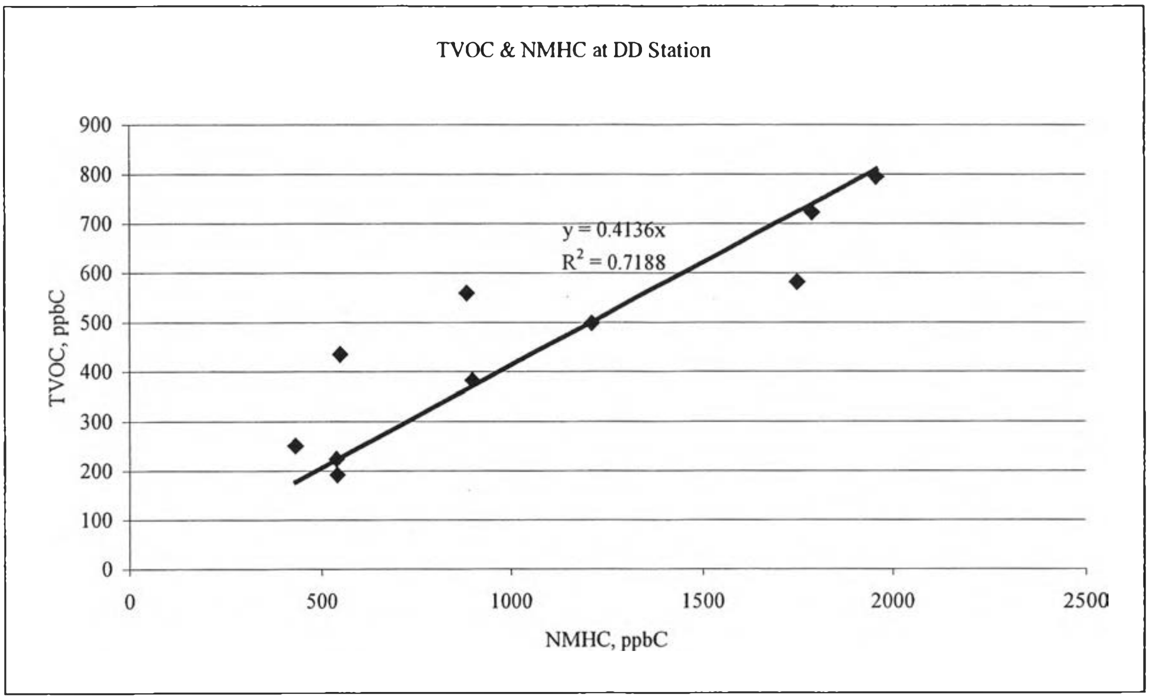

Figure 5.3 Relationship of TVOC and NMHC at DD Station

5.2 Benzene Concentration and the Benzene to Toluene Ratio

5.2.1 Spatial and Temporal Distribution of Benzene Concentrations

Benzene concentrations averaged around 35.0 - 56.8 ppbC during the SW monsoon season and from 9.5 - 30.3 ppbC during the NE monsoon season. DD station recorded the highest average concentrations during both monsoon seasons. RB station had average concentrations higher than either JK or BS stations during the SW monsoon but had the lowest concentrations in the NE monsoon (Table 5.2 and Figure 5.4).

Table 5.2 Benzene Concentrations

Unit: ppbC

Date	SW				NE			
	DD	**JK**	**BS**	**RB**	**DD**	**JK**	**BS**	**RB**
Monday	71.2	50.2 5.6*	21.3	52.1	35.1 72.2	20.1 11.6	12.8	6.8
Tuesday	59.4	13.1	72.8	201.2 6.2*	41.0	12.1	10.2	9.3 4.6
Wednesday	-	49.3	96.3 7.4*	4.7	25.0 18.6	20.6	16.9 5.9	8.8 10.2
Thursday	54.4	28.8	6.6	25.7	33.8	12.5 26.8	9.2 11.9	5.8
Friday	23.8	54.4	23.7	11.5	28.9	17.4	10.0	13.4 14.0
Saturday	-	84.1 6.1	9.2	35.5	18.0	6.3	13.2 19.9	17.2
Sunday	123.0 8.9*	57.5	42.5	-	18.7 11.4	-	29.8	5.2
Maximum	**123.0**	**84.1**	**96.3**	**201.2**	**72.2**	**26.8**	**16.9**	**17.2**
Average	**56.8**	**38.8**	**35.0**	**48.1**	**30.3**	**15.9**	**14.0**	**9.5**
Minimum	**8.9**	**5.6**	**6.6**	**4.7**	**11.4**	**6.3**	**5.9**	**4.6**

* Declared to be holidays for the APEC Conference

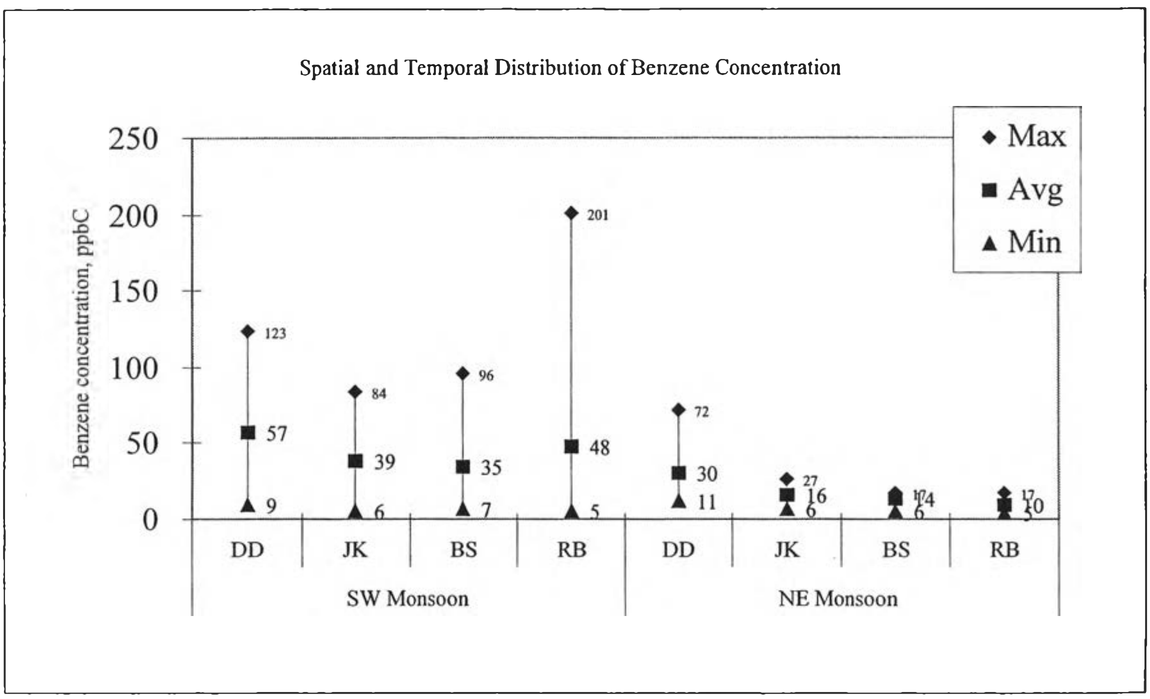

Figure 5.4 Spatial and Temporal Distribution of Benzene in Bangkok

Benzene concentrations in ambient air came from various emission sources. Among the 9 emission sources of this study, it was found that only 6 sources recorded a benzene fraction and were ordered as follows: smoke of biomass burning at 0.3949, exhaust gas of diesel vehicles at 0.2677, smoke of barbequing food at 0.1901, exhaust gas of gasoline vehicles at 0.1093, vapor of gasoline at 0.0544 and flue gas from fuel oil boilers at 0.0464. The remaining emission sources: vapor of solvent-based paints, thinners and air samples from municipal waste disposal had no detectable benzene concentrations.

5.2.2 Comparison to Other Studies

Data from WHO (2000), reported ambient benzene concentrations in many countries range between 0.96 - 27.46 ppbC. It also reported that benzene concentrations released from refueling activities may range from 18.8 to 50,780.8 ppbC (Table 5.3).

Laowakul, et al. (2003) reported benzene concentrations in 4 areas at roadsides in Bangkok: Yoawarat, Silom, Victory Monument and Ratchayothin, with concentrations of between 139.0 - 460.6 ppbC. This study found that near the road at DD station, average benzene concentrations were 30.3 - 56.8 ppbC. At the commercial and residential areas north and south of Bangkok: JK station, BS station and the industrial area south of Bangkok: RB station the average benzene concentrations were 15.9 - 38.8, 14.0 - 35.0 and 9.5 - 48.1 ppbC. Table 5.3 compares benzene concentrations found in other places.

Table 5.3 Benzene Concentrations found in Selected Locations

Unit: ppbC

Cities	Place/Activities	Benzene Concentration
1. USA (WHO, 2000)	Remote areas	0.96
	Rural	2.82
	Urban/suburban	10.8
2. Germany (WHO, 2000)	Countrywide	1.88-18.81
3. Canada (WHO, 2000)	Countrywide	2.26-27.46
4. Sweden (WHO, 2000)	17 towns	6.2-19.56
	During refueling	18.8-50,780.8
5. Bangkok, 2002 (Laowakul, et al., 2003)	Roadside	139.2-460.6
6. Bangkok, 2003-2004 (This study)	Roadside	30.3-56.8
	Urban	9.5-48.1

5.2.3 Fraction of Benzene in Emission Sources

Among the 9 emission sources in this study, it was found that smoke of biomass burning had the highest proportion of benzene. The second highest was exhaust gas from diesel vehicles followed by smoke from food barbequing and exhaust gas of gasoline vehicles (Table 5.4).

Table 5.4 Fraction of Benzene in the 9 Emission Sources

. Emission Source Profiles	Fraction of Benzene
1. Smoke of biomass burning	0.3949
2. Exhaust gas of diesel vehicles	0.2677
3. Smoke of barbequing food cooking	0.1901
4. Exhaust gas of gasoline vehicles	0.1093
5. Vapor of gasoline	0.0544
6. Flue gas from fuel oil boilers	0.0464
7. Vapor of solvent-based paints	0.0000
8. Thinner	0.0000
9. Air samples from Municipal waste disposal site	0.0000

5.2.4 Health Implications

Benzene is a carcinogenic substance with no safe level of exposure. Therefore, WHO suggested guideline concentrations of airborne benzene associated with an excess lifetime risk of $1/10^4$, $1/10^5$ and $1/10^6$ at 31.97, 3.20 and 0.0320 ppbC, respectively. From benzene concentrations found in Bangkok ranging from 9.5 - 56.8 ppbC, people in Bangkok face a high risk of cancer from benzene. Important sources of benzene are not only from vehicles but also from other fugitive sources such as the burning biomass and food barbequing. This study found that the fractions of benzene in biomass burning and food barbequing are the first and the third highest among the 9 emission source profiles.

5.2.5 Benzene to Toluene Ratio

Scheff and Wadden (1993) used the benzene to toluene ratio to indicate the source of VOCs from vehicles. The ratio of benzene to toluene from vehicles is normally 0.5. The study of Laowakul, et al. (2003) reported that the benzene to toluene ratios in Bangkok were 0.2 - 0.4.

This study found that during the SW monsoon season, benzene to toluene ratios at DD station were 0.16 - 1.53, at JK station were 0.10 - 0.68, at BS station were 0.11 - 1.63, and at RB station were 0.13 - 0.84. During the NE monsoon season, the ratios of benzene to toluene were as follows: DD station from 0.24 - 0.55, JK station from 0.18 - 0.29, BS station from 0.16 - 0.52, and RB station from 0.15 - 0.40 (Table 5.5). The average benzene to toluene ratios in this study are within the same range as those reported by Laowakul, et al. at 0.2 - 0.5.

The maximum value of the benzene to toluene ratio was 1.63. It was probably associated with emission sources with high benzene to toluene ratios such as smoke of biomass burning at 1.27 and smoke of barbequing food at 1.84 (Table 5.6).

Table 5.5 Benzene to Toluene Ratios in Ambient Air

Date	SW				NE			
	DD	JK	BS	RB	DD	JK	BS	RB
Monday	0.33	0.33 0.33	0.45	0.13	0.26 0.55	0.29 0.20	0.33	0.23
Tuesday	0.37	0.18	0.11	0.71 0.22	0.26	0.19	0.29	0.22 0.15
Wednesday		0.68	0.14 0.29	0.84	0.26 0.30	0.18	0.26 0.16	0.18 0.24
Thursday	0.36	0.19	0.20	0.58	0.25	0.23 0.24	0.22 0.17	0.22
Friday	1.53	0.61	0.50	0.13	0.28	0.19	0.21	0.26 0.37
Saturday		0.10 0.19	0.15	0.37	0.24	0.24	0.29 0.52	0.21
Sunday	0.16 0.26	0.13	1.63		0.29 0.24		0.36	0.40
Maximum	**1.53**	**0.68**	**1.63**	**0.84**	**0.55**	**0.29**	**0.52**	**0.40**
Average	**0.50**	**0.30**	**0.43**	**0.43**	**0.29**	**0.19**	**0.28**	**0.25**
Minimum	**0.16**	**0.10**	**0.11**	**0.13**	**0.24**	**0.18**	**0.16**	**0.15**

Table 5.6 Benzene to Toluene Ratios of the 9 Emission Sources

Emission Source Profiles	Benzene to Toluene Ratio
1. Smoke of biomass burning	1.27
2. Exhaust gas of diesel vehicles	1.38
3. Smoke of barbequing food cooking	1.84
4. Exhaust gas of gasoline vehicles	0.35
5. Vapor of gasoline	0.31
6. Flue gas from fuel oil boilers	0.13
7. Vapor of solvent-based paints	not detected
8. Thinners	not detected
9. Air samples from Municipal waste disposal site	not detected

5.3 Speciated VOC Ambient Concentration

5.3.1 Spatial & Temporal Distribution of Speciated VOC Ambient Concentration

From the fractions of 18 VOCs at DD, JK, BS and RB stations (Table 5.7) it was found that during both monsoon seasons the highest VOC found at all stations was toluene. The high ambient toluene concentration should indicate the contribution from sources with high toluene emission such as gasoline vehicles, fuel oil boilers, thinners and municipal waste disposal (Table 5.8).

Table 5.7 Fractions of 18 VOCs in Ambient Air

VOC Species	SW				NE			
	DD	**JK**	**BS**	**RB**	**DD**	**JK**	**BS**	**RB**
1-pentene	0.0144	0.0143	0.0128	0.0113	0.0100	0.0182	0.0112	0.0139
n-pentane	0.0889	0.0756	0.0693	0.0592	0.0974	0.0796	0.0792	0.0695
Trans-2-pentene	0.0208	0.0185	0.0100	0.0093	0.0171	0.0412	0.0125	0.0339
Isoprene	0.0281	0.0438	0.0429	0.0353	0.0309	0.0357	0.0443	0.0571
2-methylpentane	0.0219	0.0596	0.0279	0.0374	0.0489	0.0829	0.0758	0.0717
Cyclopentane	0.0557	0.0229	0.0438	0.0345	0.1005	0.0432	0.0484	0.0270
3-methylpentane	0.0697	0.0638	0.0489	0.0487	0.0981	0.0816	0.0839	0.0630
n-hexane	0.0393	0.0355	0.0332	0.0446	0.0544	0.0474	0.0504	0.0403
Cyclohexane	0.0476	0.0069	0.0135	0.0515	0.0497	0.0451	0.0389	0.0359
Benzene	0.0763	0.0760	0.0962	0.0990	0.0737	0.0669	0.0801	0.0742
2,2,4-trimethylpentane	0.0084	0.0068	0.0062	0.0065	0.0041	0.0043	0.0079	0.0073
n-heptane	0.0214	0.0210	0.0277	0.0234	0.0281	0.0263	0.0312	0.0264
Toluene	**0.2078**	**0.2584**	**0.2639**	**0.2618**	**0.2571**	**0.3076**	**0.2989**	**0.3086**
n-octane	0.0092	0.0120	0.0099	0.0110	0.0076	0.0068	0.0086	0.0116
m/p-xylene	0.1128	0.1205	0.1230	0.1245	0.0829	0.0740	0.0794	0.0846
n-nonane	0.0290	0.0391	0.0384	0.0383	0.0090	0.0111	0.0166	0.0250
1,3,5-trimethylbenzene	0.1366	0.0634	0.0765	0.0526	0.0221	0.0163	0.0176	0.0194
n-decane	0.0123	0.0618	0.0558	0.0511	0.0083	0.0121	0.0150	0.0307
	1	1	1	1	1	1	1	1

Table 5.8 Fractions of the 9 Emission Source Profiles

VOC species	Fraction								
	GV	VG	DV	FB	BB	BBQ	LT	VP	MW
1- Pentene	0.0068	0.0125	0.0855	0.0014	0.0163	0.0930	0.0000	0.0000	0.0000
n-Pentane	0.0746	0.1892	0.0348	0.0079	0.0214	0.1028	0.0000	0.0000	0.0184
trans-2-Pentene	0.0169	0.0200	0.0155	0.0043	0.0117	0.0164	0.0000	0.0000	0.0000
Isoprene	0.0016	0.0000	0.0003	0.0000	0.0487	0.0151	0.0000	0.0000	0.0019
2-Methylpentane	0.0832	**0.2275**	0.0995	0.0470	0.0457	0.0089	0.0000	0.0000	0.0032
Cyclopentane	0.0032	0.0000	0.0027	0.0003	0.0008	0.0828	0.0000	0.0000	0.0000
3-Methylpentane	0.0572	0.1299	0.0347	0.0682	0.0095	0.0068	0.0000	0.0000	0.0049
n-Hexane	0.0572	0.1274	0.0347	0.0616	0.0157	0.0848	0.0000	0.0000	0.0149
Cyclohexane	0.0516	0.0234	0.0385	0.0312	0.0118	0.0359	0.0000	0.0000	0.0425
Benzene	0.1093	0.0544	**0.2677**	0.0464	**0.3949**	**0.1901**	0.0000	0.0000	0.0000
2,2,4-Trimethylpentane	0.0000	0.0038	0.0000	0.0086	0.0000	0.0298	0.0000	0.0000	0.0259
n-Heptane	0.0280	0.0299	0.0176	0.0343	0.0172	0.0985	0.0000	0.0000	0.0332
Toluene	**0.3103**	0.1731	0.1939	**0.3454**	0.3108	0.1033	**0.9669**	0.0635	**0.7400**
n-Octane	0.0119	0.0000	0.0148	0.0278	0.0044	0.0934	0.0000	0.2455	0.0256
m/p-Xylene	0.1841	0.0088	0.0629	0.2201	0.0583	0.0000	0.0230	**0.2964**	0.0644
n-Nonane	0.0052	0.0000	0.0245	0.0272	0.0049	0.0757	0.0000	0.2306	0.0146
1,3,5-Trimethylbenzene	0.0268	0.0000	0.0252	0.0433	0.0202	0.0000	0.0101	0.0000	0.0031
n-Decane	0.0033	0.0000	0.0598	0.0250	0.0076	0.0433	0.0000	0.1640	0.0075
Total	1	1	1	1	1	1	1	1	1

5.3.2 Comparison to Other Studies

Table 5.9 compares VOCs found in USA and Bangkok. The common VOC species found at high levels in both USA and Bangkok is toluene.

Table 5.9 Comparison of VOC species in Bangkok Ambient Air to Other Studies

Unit: ppbC

VOC Species	39 USA Cities[1] (Max)	Bangkok 2000 [2] (Background)	Bangkok 2002 [3] (Roadside)	Bangkok 2003-2004 [4] (Urban)
1-Pentene	-	1-3	-	2-10
n-Pentane	1,450	7-27	-	10-69
trans-2-Pentent	-	1-6	-	2-15
Isoprene	-	0-18	-	7-18
2-Methylpentane	647	11-36	-	8-34
Cyclopentane	-	1-3	-	4-41
3-Methylpentane	351	7-22	-	8-58
n-hexane	601	4-18	-	5-32
Cyclohexane	-	3-7	-	2-68
Benzene	273	6-27	139.2-460.6	10-57
2,2,4-Trimethylpentane	-	0-6	-	1-6
n-Heptane	233	2-10	-	4-19
Toluene	**1,299**	**36-96**	**571.3-1,386.1**	**40-223**
n-Octane	-	1-3	-	1-13
m/p-Xylene	338	12-42	48.7-295.1	11-182
n-Nonane	-	0-1	-	1-62
1,3,5-Trimethylbenzene	-	3-11	0-96.5	2-182
n-Decane	-	0-2	-	3-153

Sources: 1. Weeks, et al., 2001

2. Limpaseni, et al., 2003

3. Laowakul, et al., 2003

4. This Study

Note: - not applicable

5.4 Emission Source Profiles

Emission source profiles of vehicles of both the exhaust gas and the vapor showed that the vapor of gasoline had low molecular weight VOCs at higher proportions than the exhaust gas from gasoline and diesel vehicles. While the emission source profiles of boilers, thinners and paints had large molecular weight VOCs ranging from toluene to n-decane species, emission source profiles of biomass burning and food barbequing had high molecular weight VOCs of benzene to toluene (Figures 5.5-5.7). The different pattern of each emission source was important in interpretations of source contributions.

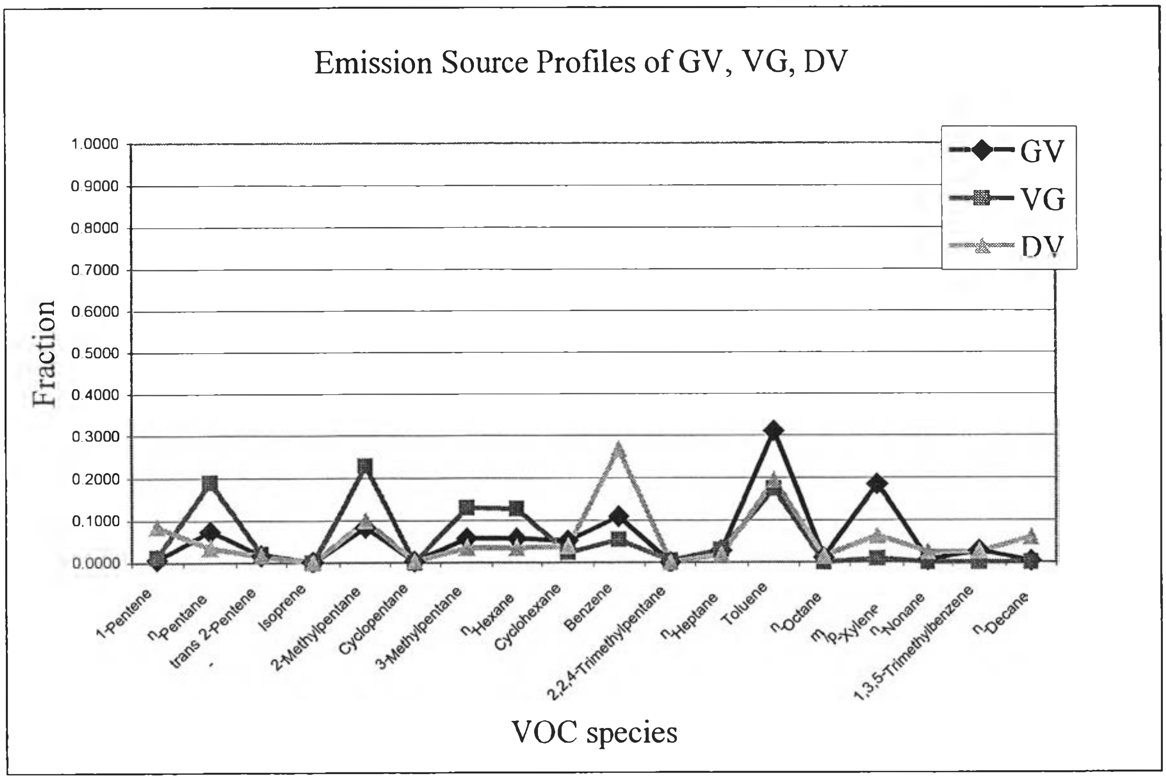

Figure 5.5 Comparison of Emission Source Profiles of GV, VG and DV

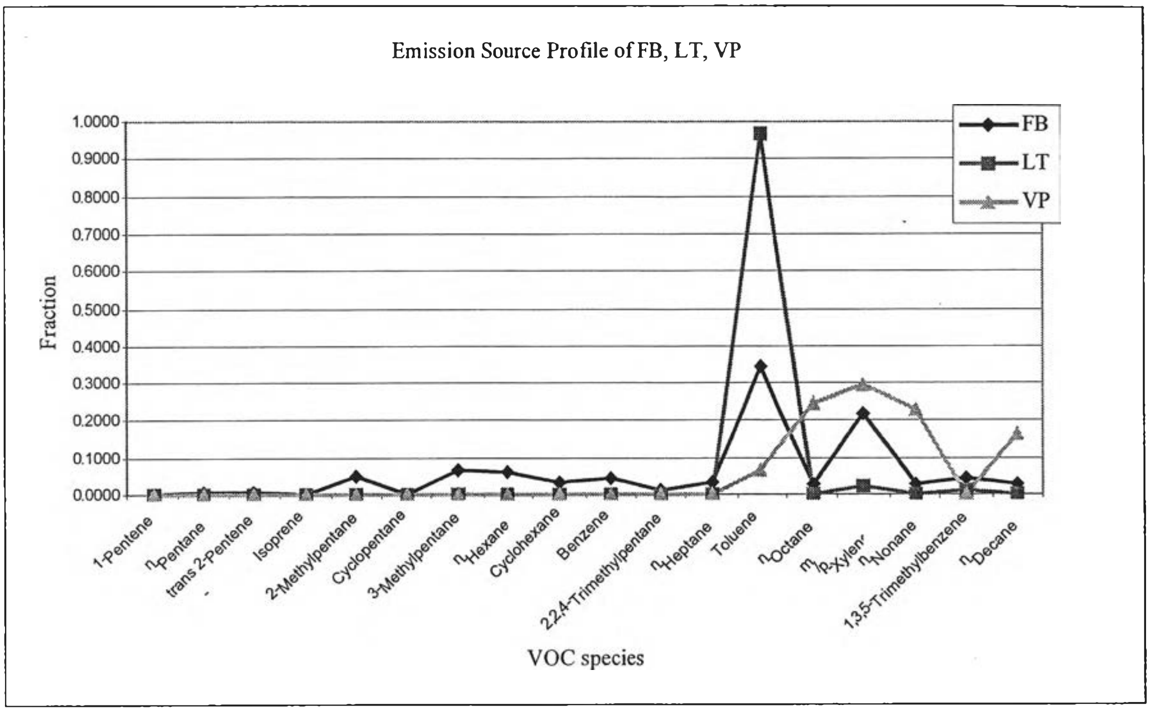

Figure 5.6 Comparison of Emission Source Profiles of FB, LT and VP

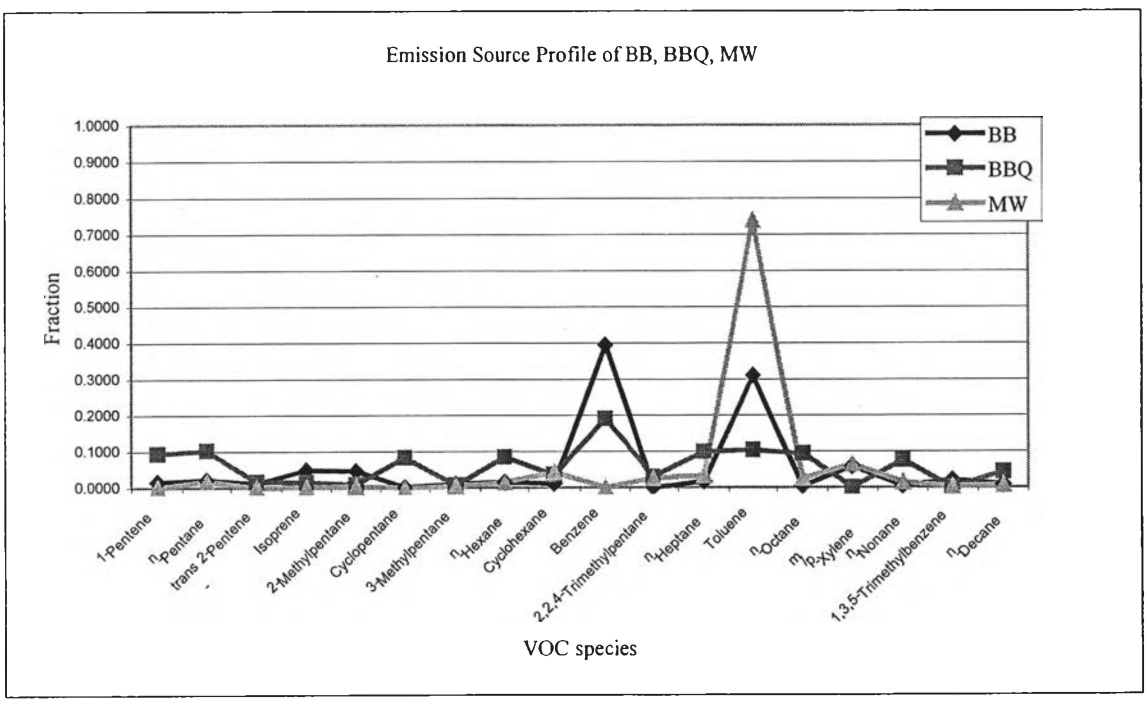

Figure 5.7 Comparison of Emission Source Profiles of BB, BBQ and MW

Fractions of VOCs in ambient air at each station during both the SW and NE monsoon seasons are of the same pattern (Figures 5.8 and 5.9).

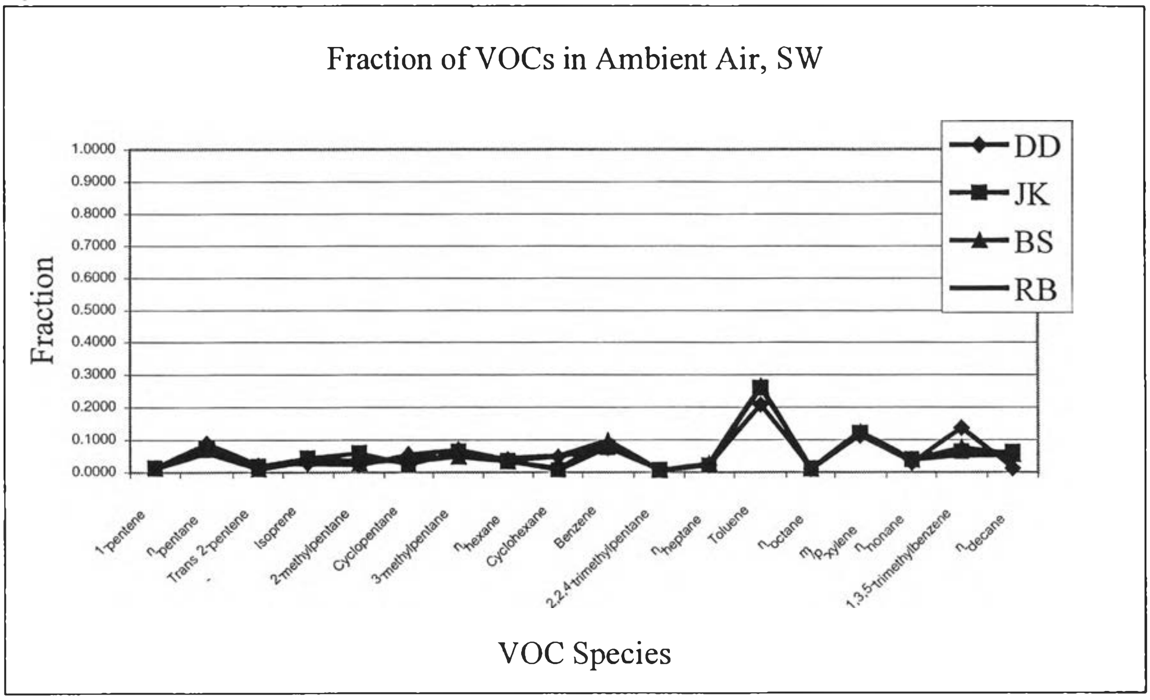

Figure 5.8 Fraction of VOCs in Ambient Air during the SW Monsoon

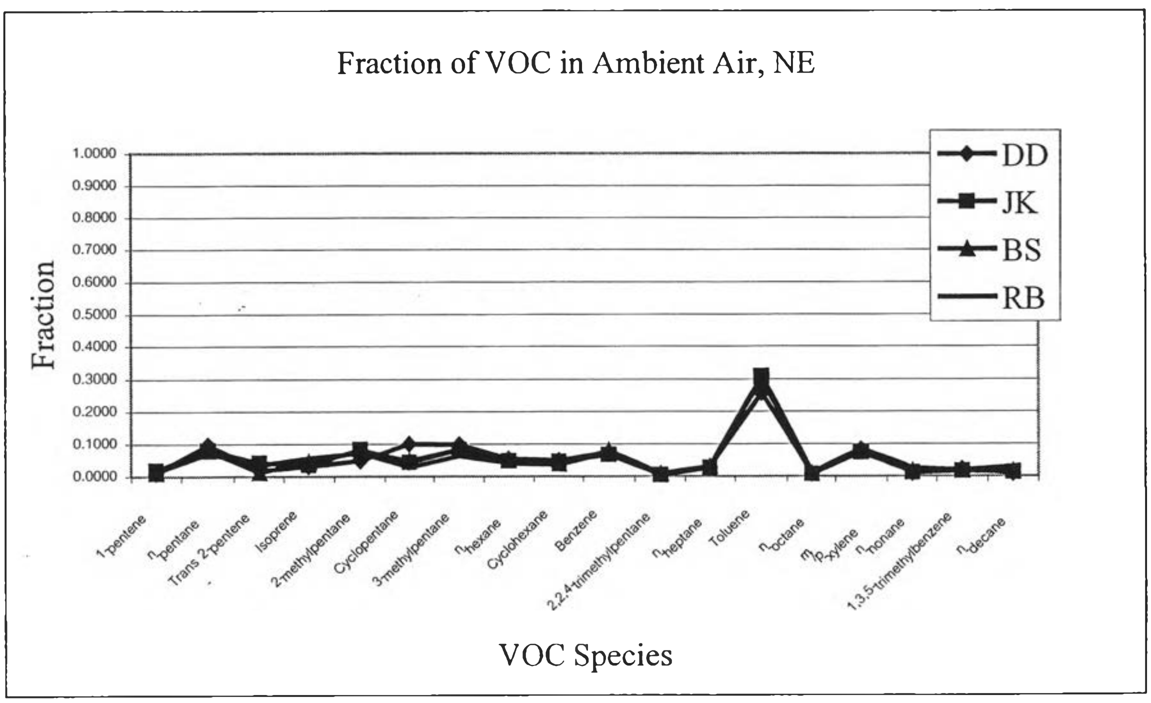

Figure 5.9 Fraction of VOCs in Ambient Air during the NE Monsoon

5.5 Source Contribution

Using specific wind directions as described in section 4.5.1, source apportionment of VOCs at 4 stations for SW and NE wind directions are shown in Table 5.10 and 5.11.

In southwest winds, all 4 areas were downwind from the industrial area south of Bangkok, in Samut Prakan province. All stations were affected by VOCs from FB at 30 - 52%. The other sources of VOCs were GV at 28% which was only found at DD station, VG at 16 - 31%, VP at 9 - 23%, BB at 19 - 52%, and unexplained sources at 3 - 15%.

Table 5.10 Source Apportionment of VOCs in Bangkok Ambient Air (Specific SW Wind Direction)

Sources	Source Contribution, %			
	DD	JK	BS	RB
GV	28	-	-	-
DV	-	-	-	-
FB	36	52	32	30
VG	-	16	31	-
VP	23	9	-	21
LT	-	-	-	-
BB	-	19	22	52
BBQ	-	-	-	-
MW	-	-	-	-
Unexplained	13	4	15	-3
Total	100	100	100	100

Under northeast wind conditions, all stations were not affected by VOCs from FB. All stations were affected by VOCs from GV at 36 - 50%. The other sources of VOCs were DV at 8 - 15%, VG at 24 - 43%, LT at 13% (found only at JK station), BBQ 22% (found only at JK station), MW at 8 - 23%, and unexplained sources at 2 - 19%.

Table 5.11 Source Apportionment of VOCs in Bangkok Ambient Air (Specific NE Wind Direction)

Sources	Source Contribution, %			
	DD	JK	BS	RB
GV	36	46	50	50
DV	8	-	-	15
FB	-	-	-	-
VG	43	-	24	-
VP	-	-	-	-
LT	-	13	-	-
BB	-	-	-	-
BBQ	-	22	-	-
MW	8	-	28	23
Unexplained	5	19	-2	12
Total	100	100	100	100

Table 5.12 shows average source contributions of VOCs from 4 stations. The average source contribution with regards to specific wind direction showed that during SW winds the most significant source of VOCs was FB at 38%. The other sources of VOCs were GV at 7%, VG at 12%, VP and LT at 13%, BB at 23%, and unexplained sources at 7%. During northeast winds, the most significant source of VOCs was GV at 46%. The other sources of VOCs were DV at 6%, VG at 16%, VP and LT at 3%, BBQ at 6%, MW at 15%, and unexplained sources at 8%.

Table 5.12 Average Source Apportionment of VOCs in Bangkok Ambient Air (Specific Wind Direction)

Sources	Average Source Contribution, %		
	SW wind direction	NE wind direction	Average
Gasoline vehicles	7	46	26
Diesel vehicles	-	6	3
Fuel oil boilers	38	-	19
Vapor of gasoline	12	16	14
Vapor of paint and thinner	13	3	8
Biomass burning	23	-	12
Food barbequing	-	6	3
Municipal waste	-	15	8
Unexplained	7	8	7
Total	100	100	100

Tables 5.13–5.16 show source contributions of VOCs at the 4 stations from July 2003 to February 2004 grouped into the SW and NE monsoon seasons using all data, regardless of wind direction.

Table 5.13 Source Apportionment of VOCs at DD Station (All Wind Directions)

Date	Source Contribution, %										Total
	GV	DV	VG	FB	VP	LT	BB	BBQ	MW	Unexplained	
27 Jul 03	28	0	0	36	23	0	0	0	0	14	100
13 Oct 03	48	0	0	11	0	0	0	12	18	10	100
SW	**38**	**0**	**0**	**24**	**11**	**0**	**0**	**6**	9	**12**	**100**
6 Nov 03	30	5	49	0	0	0	0	0	7	8	100
12 Nov 03	30	7	46	0	0	0	0	0	7	10	100
18 Nov 03	63	0	23	0	0	0	0	0	6	8	100
24 Nov 03	32	10	47	0	0	0	0	0	10	1	100
30 Nov 03	30	15	28	0	0	0	0	0	10	7	100
6 Dec 03	39	10	44	0	0	0	0	0	7	0	100
12 Dec 03	30	6	51	0	0	0	0	0	9	3	100
4 Feb 04	64	0	0	0	0	0	0	36	0	1	100
16 Feb 04	50	0	21	0	0	0	10	0	0	19	100
22 Feb 04	67	0	0	0	0	0	0	18	0	14	100
NE	**44**	**5**	**31**	**0**	**0**	**0**	**1**	**5**	**6**	**8**	**100**

Table 5.14 Source Apportionment of VOCs at JK Station (All Wind Directions)

Date	Source Contribution, %										Total
	GV	DV	VG	FB	VP	LT	BB	BBQ	MW	Unexplained	
28 Jul 03	0	0	16	52	9	0	19	0	0	4	100
26 Sep 03	0	0	52	23	0	0	25	0	0	0	100
2 Oct 03	0	10	51	26	0	15	0	0	0	-1	100
8 Oct 03	0	0	26	0	17	0	52	0	0	5	100
14 Oct 03	0	46	37	0	0	15	0	0	0	2	100
SW	**0**	**11**	**36**	**20**	**5**	**6**	**19**	**0**	**0**	**3**	**100**
7 Nov 03	58	0	0	0	0	11	0	14	0	17	100
13 Nov 03	44	0	0	0	0	15	0	21	0	20	100
19 Nov 03	65	0	26	0	2	0	0	0	4	2	100
5 Feb 04	46	0	0	0	0	16	0	20	0	18	100
23 Feb 04	53	0	0	0	0	14	0	18	0	15	100
NE	**53**	**0**	**5**	**0**	**0**	**11**	**0**	**15**	**1**	**15**	**100**

Table 5.15 Source Apportionment of VOCs at BS Station (All Wind Directions)

Date	Source Contribution, %										Total
	GV	DV	VG	FB	VP	LT	BB	BBQ	MW	Unexplained	
28 Sep 03	0	0	0	39	0	0	62	0	0	-1	100
4 Oct 03	0	0	30	31	0	0	21	0	0	18	100
SW	**0**	**0**	**15**	**35**	**0**	**0**	**42**	**0**	**0**	**8**	**100**
9 Nov 03	37	0	15	0	0	0	0	0	42	7	100
15 Nov 03	56	0	9	0	0	0	0	0	44	-8	100
27 Nov 03	47	0	46	0	0	0	0	0	20	-13	100
3 Dec 03	59	0	15	0	0	0	0	0	39	-13	100
9 Dec 03	42	0	35	0	0	0	0	0	13	10	100
7 Feb 04	86	8	0	0	0	0	0	0	0	7	100
19 Feb 04	70	4	0	0	0	0	0	0	18	8	100
25 Feb 04	64	7	0	0	0	0	0	0	21	9	100
NE	**58**	**2**	**13**	**0**	**0**	**0**	**0**	**0**	**22**	**5**	**100**

Table 5.16 Source Apportionment of VOCs at RB Station (All Wind Directions)

Date	Source Contribution, %										Total
	GV	DV	VG	FB	VP	LT	BB	BBQ	MW	Unexplained	
4 Aug 03	0	0	0	30	21	0	52	0	0	-3	100
15 Oct 03	77	13	0	0	0	0	0	0	0	10	100
21 Oct 03	58	17	0	0	0	0	0	0	21	4	100
SW	**45**	**10**	**0**	**10**	**7**	**0**	**17**	**0**	**7**	**4**	**100**
14 Nov 03	37	15	0	0	0	0	0	0	34	13	100
20 Nov 03	54	10	0	0	0	0	0	0	19	16	100
26 Nov 03	47	14	0	0	0	0	0	0	22	17	100
2 Dec 03	53	10	0	0	0	0	0	0	21	15	100
8 Dec 03	48	19	0	0	0	0	0	0	20	13	100
14 Dec 03	64	17	0	0	0	0	0	0	18	1	100
6 Feb 04	50	21	0	0	0	0	0	0	16	14	100
24 Feb 04	0	19	0	49	0	0	0	0	12	20	100
NE	**44**	**16**	**0**	**6**	**0**	**0**	**0**	**0**	**20**	**14**	**100**

Tables 5.17 and 5.18 summarize the source contribution of VOCs in Bangkok ambient air using all wind directions during the SW and NE monsoon seasons at each station.

Table 5.17 Source Apportionment of VOCs in Bangkok Ambient Air (All Wind Directions during the SW Monsoon Season)

Sources	Source Contribution, %			
	DD	JK	BS	RB
GV	38	-	-	45
DV	-	11	-	10
FB	24	20	35	10
VG	-	36	15	-
VP	11	5	-	7
LT	-	6	-	-
BB	-	19	42	17
BBQ	6	-	-	-
MW	9	-	-	7
Unexplained	12	3	8	4
Total	100	100	100	100

Table 5.18 Source Apportionment of VOCs in Bangkok Ambient Air (All Wind Directions during the NE Monsoon Season)

Sources	Source Contribution, %			
	DD	JK	BS	RB
GV	44	53	58	44
DV	5	-	2	16
FB	-	-	-	6
VG	31	5	13	-
VP	-	-	-	-
LT	-	11	-	-
BB	1	-	-	-
BBQ	5	15	-	-
MW	6	1	22	2
Unexplained	8	15	5	14
Total	100	100	100	100

Table 5.19 shows the average source apportionment of VOCs from the 4 stations. During the SW monsoon season, VOCs from fuel oil boilers affected VOC ambient concentrations by around 22%. It was the most significant source during this season. The opposite situation occured during the NE monsoon season when fuel oil boilers affected VOC ambient concentrations by only 2%. The reason for this is that all stations were downwind from an industrial area during the southwest monsoon season but upwind from it during the northeast monsoon season.

Table 5.19 Average Source Apportionment of VOCs in Bangkok Ambient Air (All Wind Directions)

Sources	Average Source Contribution, %		
	SW monsoon season	NE monsoon season	Average
Gasoline vehicles	21	50	36
Diesel vehicles	5	6	6
Fuel oil boilers	22	2	12
Vapor of gasoline	12	12	12
Vapor of paint and thinner	8	3	5
Biomass burning	19	-	10
Food barbequing	2	5	3
Municipal waste	4	12	8
Unexplained	7	10	8
Total	100	100	100

The average results show that the source contribution from the exhaust gas of both gasoline vehicles and diesel vehicles was 42%. The source contribution from fuel oil boilers was 12%. The remaining source contribution were from fugitive sources and area sources: vapor of gasoline and vapor of solvent-based paints and thinners, biomass burning, food barbequing and municipal waste disposal was 38%. Figures 5.10 and 5.11 show source apportionment of VOCs in Bangkok ambient air during the two monsoon seasons.

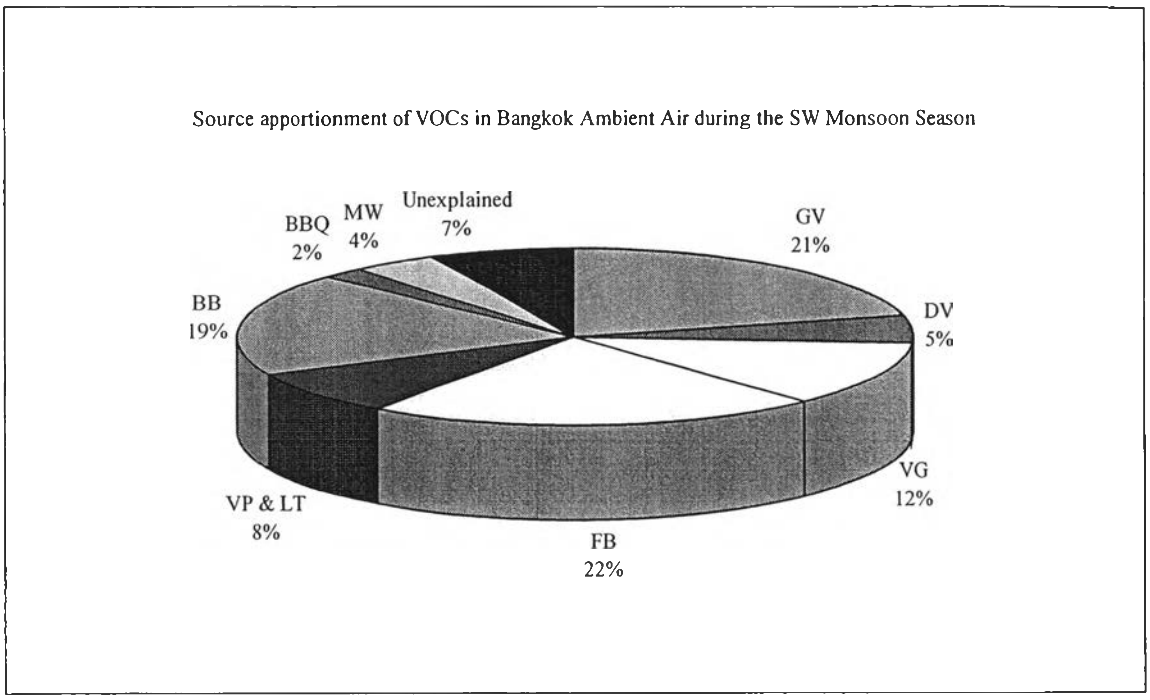

Figure 5.10 Source Apportionment of VOCs in Bangkok Ambient Air during the SW monsoon Season

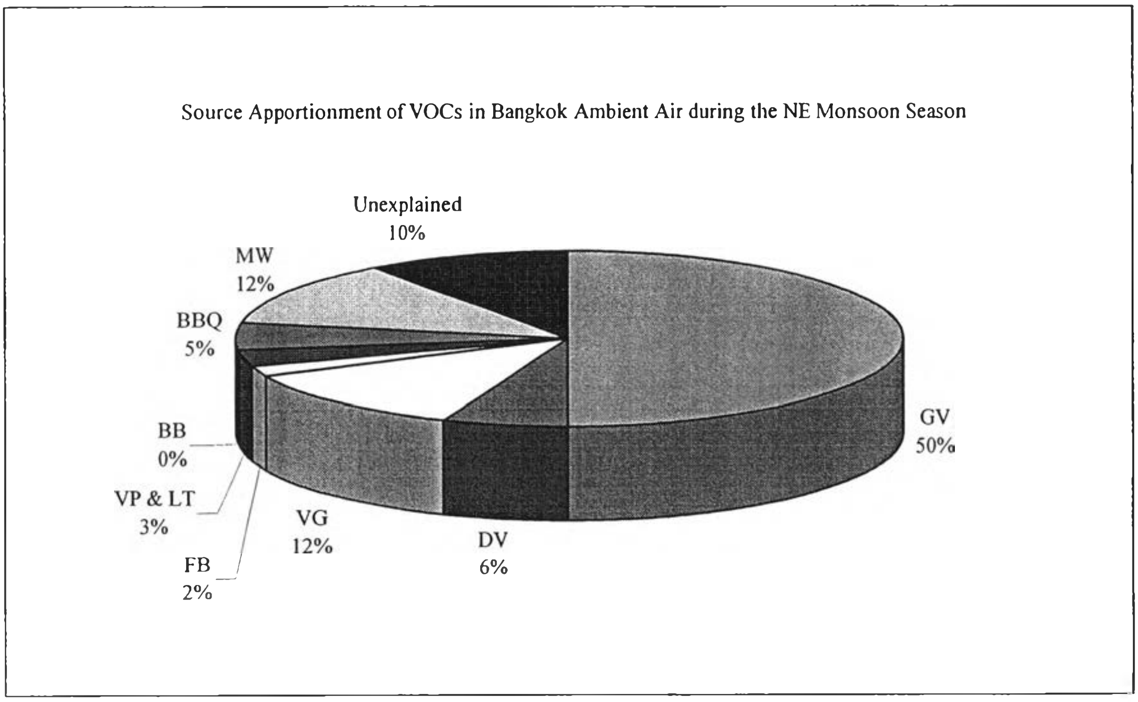

Figure 5.11 Source Apportionment of VOCs in Bangkok Ambient Air during the NE monsoon Season

Using two approaches: that with specific wind direction and that regardless of wind direction, the results show that the average source apportionment of VOCs by both approaches are quite similar. However using data from all wind directions, yields more samples and thus covers more sources than using specific wind direction with a limited number of samples (Table 5.20).

Table 5.20 Comparison of Source Contribution by the Different Approaches

Sources	Average Source Contribution, %					
	Specific wind directions			All wind directions		
	SW	NE	Average	SW	NE	Average
Gasoline vehicles	7	46	**26**	21	50	**36**
Diesel vehicles	-	6	**3**	5	6	**6**
Fuel oil boiler	38	-	**19**	22	2	**12**
Vapor of gasoline	12	16	**14**	12	12	**12**
Vapor of paint and thinner	13	3	**8**	8	3	**5**
Biomass burning	23	-	**12**	19	-	**10**
Food barbequing	-	6	**3**	2	5	**3**
Municipal waste	-	15	**8**	4	12	**8**
Unexplained	7	8	7	7	10	**8**
Total	100	100	**100**	100	100	**100**

Table 5.21 compares the source contribution of VOCs in this study to the results of CMB modeling on one day in March 2000 and to the Bangkok emission inventories base year of 1997 and 2000 and to the emission inventories of 15 countries in the EU. VOCs from vehicle traffic in the EU emission inventory show similarity to the results from this study. The sources of VOCs in Bangkok ambient air primarily come from the exhaust gas of vehicles, which contribute 42%. Other important sources of VOCs not covered by the emission inventories are area and fugitive sources identified by source apportionment undertaken in this study.

Table 5.21 Comparison of Source Contribution between Emission Inventories and the Receptor Model

Emission Sources	Source contribution, %				
	Emission inventory 1997[1]	Emission inventory 2000[2]	EU 15 Countries	Receptor model March 2000[3]	Receptor model This study
Line source : *traffic*	95.1	60	31	33-88	
Gasoline vehicles					36
Diesel vehicles					6
Point source : boilers	0.2	0	0.4	46	12
Area source :					
Refueling	4.7	3		0	12
Usage of solvent containing products		37	27	0	5
Biomass burning				12-61	10
Food barbequing					3
Municipal waste			7		8
Unexplained					8

1 PCD, 2001

2 Pongrueksa, 2001

3 Suwattiga and Limpaseni, 2003

Note: Classification of emission sources referred to the original emission inventory

[shaded box] Not applicable

5.6 Control Strategy Development

Source apportionment of VOCs is important information for policy making in order to set up a control strategy for ozone. If the emission inventory excludes solvent containing products and other fugitive sources such as biomass burning, it may be concluded that 95% of VOCs are from vehicles (Table 5.21). Based on this information, the control strategy will concentrate on reducing VOCs from vehicles only. But in reality, even if the control strategy succeeds in controlling 100% of VOCs from vehicles, it may only control half of the actual emission sources since the source apportionment shows that half of the VOCs emissions are from sources other than vehicles. The source apportionment in this study indicates that area sources such as refueling and usage of solvent containing products and other fugitive sources such as biomass burning, food barbequing and municipal waste disposal may contribute up to half the VOCs emission in areas of Bangkok. The effective control strategy in reducing ozone pollution in Bangkok needs to consider additional sources identified from this source apportionment study.

The source apportionment results indicate the weakness in the existing emission inventory and stresses the need to put greater effort to include the missing area sources and fugitive sources contributing to VOCs emissions.

The source apportionment results in this study also provide greater details of source contribution both temporally and spatially. Since the ozone episode mainly occurs in the dry seasons, especially during the months of November to March, a control strategy should also be enforced more strictly during the high ozone episode. Incidentally, the biomass burning of agriculture waste also peaks during the months of February to March and places biomass burning high on the list of emission sources that need to be controlled during the ozone episode. Besides controlling the ozone episode, it helps to reduce the benzene concentration in ambient air since benzene is the highest fraction in biomass burning profiles.