CHAPTER 4

RESULTS AND DISCUSSIONS

In this study, the vapor recovery unit was a type called carbon vacuum adsorption vapor recovery (CVA). It has been installed at the Shell of Thailand and Fuel Pipeline Transportation Limited bulk gasoline terminal. The operational function of the unit was described in 3.1.

The aim of this study was to determine the composition of evaporative emissions from gasoline transfer operation at bulk gasoline terminal. Moreover, evaluation of the VRU' s efficiency for controlling VOCs and HAPs were also included in this study. The results from the experiments were integrated to the economic for evaluation of the cost-effectiveness of the vapor recovery unit and the possibility implementation to the country policy on VOCs/hazardous VOCs emissions at bulk gasoline terminals.

4.1 Volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) in gasoline vapor at bulk gasoline terminal

The results of the volatile organic compounds presented in gasoline emission at both inlet (uncontrolled) and outlet (controlled) of VRU. The samples were analysed by gas chromatography - mass spectrometry (GC/MS) at the optimum conditions, the chromatogram shown a huge of either identified or unidentified compounds. The identification with the chromatogram obtained from GC/MS was found that it was more than 20 hit compounds listed in the GC/MS's library (**Appendix B**). The exact identification of those compounds, their standard were needed for the compound (chromatogram peak) confirmation. Therefore, to cut of the cost of analysis for unnecessary peaks the study was limited only the major volatile hydrocarbons and the HAPs. The chromatograms of both inlet and outlet samples and also some results that searched hit list of GC/MS shown in **Appendix B**.

However, the identified compounds that found at the inlet and outlet samples were mostly the same as the target of HAPs in this study i.e. benzene (B), toluene (T), ethylbenzene (EB), all three isomer of xylene (para-, meta-, ortho-, X), methyl tert-butyl ether (MTBE) and 1-butene.

The identified compounds both at the inlet and outlet of VRU were all in the list of hazardous air pollutants of the Clean Air Act of U.S EPA (Hazardous Air Pollutant List; Modification, 61 FR 30816, June 18, 1996). The other HAPs that also found in gasoline vapor were napthalene, cumene, n-hexane and 2,2,4-trimethylpentane or iso-octane which also listed by U.S.EPA, Office of Air Quality Planning and Standard, (1994).

The information of gasoline composition were limited by its diversify composition among the sources and countries. The related studies that revealed the composition of gasoline emission reported by Air & Waste technology Co., Ltd in 2001 for the PCD, Thailand. The samples taken at Bangchak refinery area and found those thirty eighth hydrocarbons from total of forty five compounds in the study. There were ethene, acetylene, ethane, propene, propane, propyne, isobutane, I-butene, 1-butene, n-butyne, trans-2-butene, cis-2-butene, 3-methyl-1-butene, isopentane, 1-pentene, isoprene, trans-2-pentene, 2-methyl-2-butene, cyclopentane, 2-methylpentane, 3- methylpentane, 1-hexane, n-hexane, 2-methyl-2-pentene, benzene, cyclohexane, n-heptane, toluene, n-octane, ethylbenzene, m,p-xylenes, o-xylene, 1,3,5–trimethylbenzene, 1,2,4- trimethylbenzene and decane.

4.2 Control efficiency of VRU for VOCs and HAPs

The total of sixty-eight samples from both sites (inlet and outlet) were analysed for total VOCs at the Automotive Emission Laboratory, Pollution Control Department. The HAPs that measured were benzene, toluene, ethylbenzene, m-xylene, o-xylene and methyl tert-butyl ether (MTBE). The results from these studies, VOCs and the HAPs concentration from the Shell of Thailand and FPT shown in Table 4.1 and 4.2 respectively.

The results show that MTBE concentration was the most frequently found and the highest concentration. Benzene and toluene were shown in the second after MTBE while the rest were rarely found and also at the low concentration.

Table 4.1 : The concentration of total VOCs and HAPs at sampling sites of VRU (The Shell of Thailand)

Date	Sampling Time	Temperature (C)			Gasoline Loaded (Liter)			MTBE (ug/l)		Benzene (ug/l)		Toluene (ug/l)		Ethylbenzene (ug/l)	
		ambient	inlet	outlet	Diesel	95	91	inlet	outlet	inlet	outlet	inlet	outlet	inlet	outlet
Sunday	11.28-12.28 AM	32	34	32.5	57,005	54,003	41,999	39,851.04	103.82	5,900.92	73.68	na	na	3,624.40	0
1/12/02	12.45-1.15 PM	32.5	35	33	86,996	57,006	48,007	75,969.16	82.12	1,547.32	65.12	na	na	0.00	0
Monday	10.58-11.58 PM	28	29	28.5	212,027	309,038	158,991	428.56	0	767.44	14.66	1,626.84	31.23	0	0
2/12/02	00.05-1.05 AM	27	28	27.5	159,014	198,023	117,002	1,062.00	23.60	1,356.08	7.64	2,072.00	0	0	0
Thuesday	10.48-11.48 AM	28	29	29.5	289,035	168,009	117,039	18,443.60	0	3,877.92	48.22	na	na	0	0
3/12/02	11.59-00.59 AM	28	29	29.5	348,001	230,997	161,991	21,297.60	0	900.28	63.41	na	na	0	0
Thursday	11.03-00.03 AM	26.5	25.5	26	119,007	114,009	78,000	95,636.00	0	36,872.16	7.57	13,704.40	27.67	0	0
5/12/02	00.17-1.17 AM	26	25	25.5	84,231	72,018	56,998	2,381.24	0	5,098.32	3.12	6,832.80	0	0	0
Sunday	9.25-10.25 AM	35	36	34	26,995	50,996	32,993	32,607.20	46.78	1,440.20	64.45	na	na	0	0
8/12/02	10.55-11.55 AM	36	37.5	35.5	62,999	60,006	32,997	66,981.40	0	7,021.76	35.45	na	na	0	0
Thursday	10.20-11.20 PM	26.5	27.8	28	200,998	171,009	119,999	4,663.60	139.26	664.12	46.86	1,863.00	102.78	204.92	0
12/12/02	11.40PM-00.40 A	26	27.5	28	653,986	564,121	384,081	1,255.16	0	1,156.16	24.32	1,940.52	54.74	0	0
Thursday	10.20-11.20 PM	28	27.5	28	264,000	228,017	159,120	16,998.80	12.43	3,139.96	56.58	2,551.64	37.21	58.28	0
13/2/03	11.30PM-00.30A	28	27.5	28	216,903	162,023	108,061	69,604.00	14.07	7,942.80	64.43	6,139.60	50.79	126.48	0
Friday	10.50-11.50 PM	27	26.5	27.5	330,000	210,013	137,996	2,624.20	14.14	884.00	64.60	405.28	52.11	0	0
14/2/03	00.00-1.00 AM	26.5	26	27	155,994	180,023	110,989	9,114.40	0	1,914.68	61.65	1,057.32	38.22	0	0
Sunday	9.40-10.40 AM	33	35	32	74,991	23,996	32,996	104,736.00	0	11,283.16	9.05	9,144.00	60.08	277.52	0
16/2/03	11.00-12.00 AM	34.5	37	35.5	74,997	47,996	33,000	38,172.80	17.48	3,597.16	16.59	3,425.80	76.63	129.96	0

Table 4.1 : The concentration of total VOCs and HAPs at sampling sites of VRU (The Shell of Thailand) (con't)

Sampling Time	Temperature (C)			Gasoline Loaded (Liter)			m-xylene (ug/l)		o-xylene (ug/l)		Total VOC (ppmv)		Total VOC (mg/l)	
	ambient	inlet	outlet	Diesel	95	91	inlet	outlet	inlet	outlet	inlet	outlet	inlet	outlet
11.28-12.28 AM	32	34	32.5	57,005	54,003	41,999	1,909.24	37.93	0	0	411,101.90	76.39	739.82	0.14
12.45-1.15 PM	32.5	35	33	86,996	57,006	48,007	0	0	80.04	0	499,450.20	27.97	898.81	0.05
10.58-11.58 PM	28	29	28.5	212,027	309,038	158,991	0	0	0	0	208,068.40	80.00	374.44	0.14
00.05-1.05 AM	27	28	27.5	159,014	198,023	117,002	261.08	0	0	0	448,464.73	61.43	807.05	0.11
10.48-11.48 AM	28	29	29.5	289,035	168,009	117,039	0	0	0	0	240,719.69	94.10	433.20	0.17
11.59-00.59 AM	28	29	29.5	348,001	230,997	161,991	0	0	0	0	460,150.31	76.18	828.08	0.14
11.03-00.03 AM	26.5	25.5	26	119,007	114,009	78,000	180.48	0	0	0	889,177.50	298.72	1,600.16	0.54
00.17-1.17 AM	26	25	25.5	84,231	72,018	56,998	345.76	0	0	0	707,467.50	256.24	1,273.15	0.46
9.25-10.25 AM	35	36	34	26,995	50,996	32,993	0	0	0	0	654,179.66	112.73	1,177.26	0.20
10.55-11.55 AM	36	37.5	35.5	62,999	60,006	32,997	0	0	0	0	684,487.95	154.74	1,231.80	0.28
10.20-11.20 PM	26.5	27.8	28	200,998	171,009	119,999	0	0	0	0	274,445.78	131.90	493.89	0.24
11.40PM-00.40 AM	26	27.5	28	653,986	564,121	384,081	0	0	0	0	584,335.88	273.64	1,051.57	0.49
10.20-11.20 PM	28	27.5	28	264,000	228,017	159,120	209.20	8.83	0	0	225,977.44	220.80	406.67	0.40
11.30PM-00.30AM	28	27.5	28	216,903	162,023	108,061	378.16	10.01	88.28	0	749,102.50	301.50	1,348.08	0.54
10.50-11.50 PM	27	26.5	27.5	330,000	210,013	137,996	0	5.57	0	0	114,081.91	264.50	205.30	0.48
00.00-1.00 AM	26.5	26	27	155,994	180,023	110,989	57.28	6.62	0	0	453,808.33		816.67	-
9.40-10.40 AM	33	35	32	74,991	23,996	32,996	729.48	14.00	184.64	0	553,683.75	50.97	996.40	0.09
11.00-12.00 AM	34.5	37	35.5	74,997	47,996	33,000	381.36	15.56	90.40	0	286,047.38	66.72	514.77	0.12

Table 4.1 : The concentration of total VOCs and HAPs at sampling sites of VRU (Fuel Pipeline Transportation)

Date	Sampling Time	Temperature (C)			Gasoline loaded (Liter)		MTBE (ug/l)		Benzene (ug/l)		Toluene (ug/l)		Ethylbenzene (ug/l)	
		ambient	inlet	outlet	95	91	inlet	outlet	inlet	outlet	inlet	outlet	inlet	outlet
Tuesday	11.10-12.10 AM	34.5	38	33	19,999	6,000	8,810.80	0	1,405.60	0	2,776.20	31.64	280.04	0
21/1/03	12.30-1.30 PM	35	38	33	4,997	7,999	27,485.60	0	2,874.56	0	905.60	24.372	0	0
Wednesday	11.00-12.00 AM	32	37.5	32	12,474	25,285	21,008.00	0	4,432.12	4.06	5,592.80	31.48	131.72	0
22/1/03	1.00-2.00 PM	32.5	37.5	32	16,254	16,338	17,246.80	0	4,588.12	0	8,311.20	21.00	231.44	0
Thursday	10.50-11.50 AM	31	35.5	30.5	17,199	47,069	17,051.60	0	2,005.88	0	2,425.80	66.86	0	0
23/1/03	1.00-2.00 PM	32	36	30.5	14,364	22,562	26,985.20	0	2,966.28	1.06	2,826.64	45.54	0	0
Friday	10.45-11.45 AM	31	34	31	19,467	38,900	20,190.00	0	2,485.88	0	2,748.00	0	0	0
24/1/03	12.10-1.10 PM	31.5	36.5	31	13,041	42,012	31,877.20	0	3,377.64	0	1,885.32	24.33	0	0
Saturday	10.30-11.30 AM	31	34	31.5	12,474	76,244	19,620.40	0	2,082.48	5.80	1,093.76	17.03	0	0
25/1/03	11.50-12.50 AM	31.5	36.5	31.5	4,536	19,061	9,905.20	0	2,738.80	5.58	2,763.20	22.01	0	0
Sunday	10.40-11.40 AM	30	35	30	9,828	16,338	24,659.20	0	4,386.12	0	6,453.20	0	204.92	0
26/1/03	12.00-1.00 PM	31	35.5	31	3,402	0	60,881.04	0	6,757.08	0	5,568.40	0	0	0
Monday	11.20-12.20 AM	32	36	32.5	45,549	84,413	43,424.00	0	5,498.52	2.38	0	0	141.60	0
27/1/03	12.40-1.40 PM	33	39	33.5	12,663	31,898	18,420.40	0	4,793.32	0	0	0	141.00	0
Sunday	11.15-12.15 AM	34	39	34	19,089	54,849	113.68	0	0	0	334.48	0	0	0
2/2/03	12.30-1.30 PM	35	41.5	35	11,907	64,574	12.24	0	0	0	337.04	0	0	0

Table 4.1 : The concentration of total VOCs and HAPs at sampling sites of VRU (Fuel Pipeline Transportation) (con't)

Date	Sampling Time	Temperature (C)			Gasoline loaded (Liter)		m-xylene(ug/l)		o-xylene (ug/l)		Total VOC (ppmv)		Total VOC (mg/l)	
		ambient	inlet	outlet	95	91	inlet	outlet	inlet	outlet	inlet	outlet	inlet	outlet
Tuesday	11.10-12.10 AM	34.5	38	33	19,999	6,000	731.96	27.90	273.64	13.61	141992.40	28.27	255.53	0.051
21/1/03	12.30-1.30 PM	35	38	33	4,997	7,999	0	25.45	0	0	367,097.20	12.28	660.62	0.022
Wednesday	11.00-12.00 AM	32	37.5	32	12,474	25,285	622.08	0	146.12	0	442,509.40	40.44	796.34	0.073
22/1/03	1.00-2.00 PM	32.5	37.5	32	16,254	16,338	885.64	0	196.84	0	349,394.40	14.86	628.77	0.027
Thursday	10.50-11.50 AM	31	35.5	30.5	17,199	47,069	0	42.97	0	20.15	318,689.40	101.10	573.51	0.182
23/1/03	1.00-2.00 PM	32	36	30.5	14,364	22,562	245.12	26.22	0	0	317,518.00	75.73	571.40	0.136
Friday	10.45-11.45 AM	31	34	31	19,467	38,900	236.28	0	0	0	290,881.50	45.66	523.47	0.082
24/1/03	12.10-1.10 PM	31.5	36.5	31	13,041	42,012	0	19.85	0	0	710,245.10	29.26	1,278.15	0.053
Saturday	10.30-11.30 AM	31	34	31.5	12,474	76,244	0	0	0	0	412,689.00	137.36	742.67	0.247
25/1/03	11.50-12.50 AM	31.5	36.5	31.5	4,536	19,061	297.28	0	0	0	165,831.80	86.77	298.43	0.156
Sunday	10.40-11.40 AM	30	35	30	9,828	16,338	748.68	0	162.72	0	410,595.80	44.80	738.90	0.081
26/1/03	12.00-1.00 PM	31	35.5	31	3,402	0	401.36	0	183.36	0	590,040.00	2.43	1,061.83	0.004
Monday	11.20-12.20 AM	32	36	32.5	45,549	84,413	509.96	0	102.92	0	604,907.20	104.91	1,088.59	0.189
27/1/03	12.40-1.40 PM	33	39	33.5	12,663	31,898	663.52	0	150.52	0	361,599.20	37.50	650.73	0.067
Sunday	11.15-12.15 AM	34	39	34	19,089	54,849	113.44	0	0	0	497,722.50	108.20	895.70	0.195
2/2/03	12.30-1.30 PM	35	41.5	35	11,907	64,574	153.80	0	72.36	0	455,709.40	118.12	820.09	0.213

4.2.1 Controlled VOCs by VRU compared to the regulation

The results showed that the VOCs emitted from the vent of VRU was very low concentration and under the compliance limit of a Notification of the Ministry of Science, Technology and Environment that is gasoline emissions at bulk gasoline terminals should not be over 17 milligram of total volatile organic compounds (mg/l) per liter in emitted vapor per hour. The average VOCs emitted at the Shell of Thailand and FPT were 0.24 mg/l and 0.11 mg/l respectively.

This emission was also under the compliance limit that required for loading and unloading installations at terminals, in Europe region, i.e. the mean concentration of vapor from the exhaust of the vapor recovery unit must not exceeded 35 g/normal cubic meter (Nm^3) for any one hour.

The Best Available Control Technology (BACT) noticed by USEPA in 1991 has stated that the most stringent emission limitation of VOC at gasoline terminal achieved by carbon adsorption technique that could achieved by 95-97.5% control efficiency. Therefore, the implementation of the control device could also controlled the VOCs emit under the country regulation.

4.2.2 Control efficiency of VRU for VOCs and HAPs

The daily calculation of VRU's ability for controlling gasoline emission at both sites were shown in **Appendix C**. The summaries of control efficiencies of the unit for individual HAPs and total VOCs were presented in Table 4.3. The results showed the control efficiency of the total VOCs was over 99.9% while the individual HAP that varied from 97% to 100% for both sites. Average control efficiency for VOCs and HAPs was shown in Figure 4.1.

Table 4.3 The control efficiencies for VOCs and HAPs of Carbon Vacuum Adsorption Unit (CVA) at bulk gasoline terminals

HAP Compound	Shell			FPT		
	Average CE%	Min CE%	Max CE%	Average CE%	Min CE%	Max CE%
MTBE	99.64	97.01	99.98	100.00	100.00	100.00
Benzene	97.55	92.69	99.94	99.95	99.72	100.00
Toluene	97.32	87.14	99.80	99.10	97.24	100.00
Ethybenzene	100.00	100.00	100.00	100.00	100.00	100.00
o-Xylene	100.00	100.00	100.00	99.38	95.02	100.00
m-Xylene	97.07	88.84	98.08	98.79	89.3	100.00
Total HAP	98.60	94.28	99.63	99.54	96.88	100.00
Total VOC	99.955	99.77	99.994	99.982	99.948	99.999

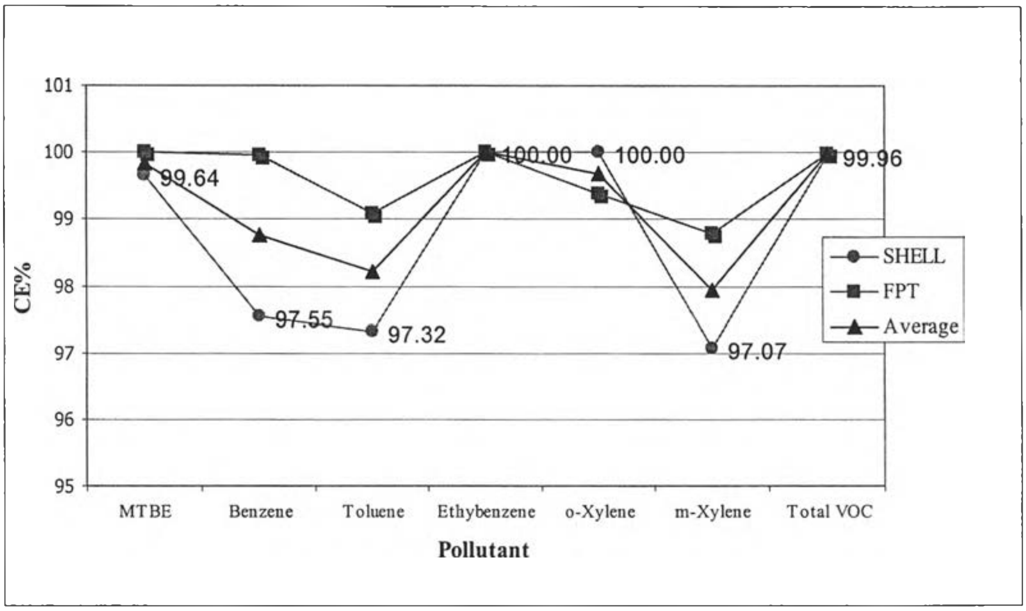

Figure 4.1 VOCs and HAPs control efficiency of CVA

From these studies, the VOCs and HAPs removal efficiencies of two units were almost the same rate which an average efficiency of 99.97% and 99.01% respectively. However, the control efficiency for individual HAP was insignificantly difference and has the similar trended for individual HAP removal efficiencies of two units. The order of HAPs control efficiency were ethylbenzene > MTBE > o-xylene > benzene > toluene > m-xylene, 100%, 99.82%, 99.69%, 98.75%, 98.21% and 97.93%, respectively. These studies indicated that the Carbon Adsorption Units tend to control

HAP emission independent of the control efficiency for VOCs and also shown that HAPs control efficiency was slightly lower than VOCs control efficiency, that was around 1%.

The results of VOCs and HAPs control efficiency by Carbon Adsorption Unit was slightly different when compared with the American Petroleum Institute in 1998. The API reported the average HAP removal efficiencies by Carbon Adsorption Unit was 99.73% and often greater than VOCs removal efficiencies averaged 97.3%.

4.3 Estimation of toxic emission loaded at bulk gasoline terminals

The control efficiency data collected can be used to derive emission factors for HAPs that allow HAP emission estimation based on the volume of gasoline loaded at facilities. Controlled emission factor for each HAP could estimate by the following equation.

$$EF_{HAPi} = \frac{(EF_{VOC})(\text{HAP to VOC\%}_i)\ (1\text{-CE\%})}{100}$$

Where :

EF_{HAPi} = controlled emission factor for HAP_i (mg-HAP_i/l-gasoline loaded)

EF_{VOC} = uncontrolled emission factor for VOC (mg-VOC/l-gasoline loaded)

HAP to VOC$\%_i$ = weight percent of HAP_i in uncontrolled gasoline vapor

CE% = control efficiency of HAP_i (percent) (from table 4.3)

Value for the uncontrolled emission factor for VOC (EF_{VOC}) and speciation of HAPs in uncontrolled gasoline vapors was varied with the different gasoline. Due to the lacking of specific information on these values in Thailand, the values for these variables were taken from U.S.EPA guidance. The uncontrolled VOC emission factor (EF_{VOC}) was available in AP-42 Table 5.2-5 and shown in Table 4..4. The individual HAP content values of uncontrolled VOC emissions (HAP to VOC%) are taken from EPA publication Gasoline Distribution Industry (Stage I)- Background Information for proposed Standards (EPA-453/R-94-002a) and shown below in Table 4.5.

EFs were calculated for the unit studied at loading operation with vapor balance service (Shell) and submerged loading using dedicated normal service (FPT).

Tables 4.6 and 4.7 shown the EFs for vapor balance service dedicated and normal service, respectively.

Table 4.4 Uncontrolled VOC emission factors for tank trucks

Loading Operation	Emission Factor, mg-VOC/l-transferred gasoline
Submerged loading	
Dedicated normal service	590
Vapor balance service	980

Source : AP-42 Table 5.2-5

Table 4.5 Uncontrolled gasoline vapor HAP-to-VOC content

HAP	HAP-to-VOC weight % by type of gasoline			
	Normal	Reformulated	Oxygenated	Reformulate &Oxygenated
MTBE	0.0	8.7	11.9	11.9
Benzene	0.9	0.4	0.7	0.4
Toluene	1.3	1.1	1.1	1.1
Ethylbenzene	0.1	0.1	0.1	0.1
Xylenes	0.5	0.4	0.4	0.4
Hexane	1.6	1.4	1.4	1.4
Isooctane[a]	0.8	0.7	0.7	0.7
Total HAP[b]	Na	12.9	16.3	16.0
Total HAP w/o MTBE[b]	4.8	na	na	na

[a] 2,2,4-trimethylpentane

[b] The total HAP ratios shown are not simply run individual HAPs but are the average of the total HAPs and therefore may not be equal to the sum of the individual average

Source : Gasoline Distribution Industry (Stage I)- Background information for Proposed Standards (EPA-453/R-94-002a)

Table 4.6 HAP EFs for carbon adsorber units at submerged loading operations using vapor balance service. (SHELL site)

HAP	Control Effic.%	Emission Factor by Gasoline Type (EF)[a] (mg-HAP/l gasoline transferred)	
		Normal	Oxygenated
MTBE	99.64	Na	0.4198
Benzene	97.55	0.2161	0.1681
Toluene	97.32	0.3414	0.2889
Ethylbenzene	100	0	0
Xylenes[b]	98.53	0.0720	0.0576
Sum HAPs[c]	98.60	0.6295	0.9344

[a] Calculated using AP-42 uncontrolled VOC emission factor of 980 mg/l and vapor HAP to VOC content listed in Table 4.5

[b] Xylenes calculated using the average CE% of m-xylene and p-xylene

[c] Sum of five HAPs evaluated in this study

Table 4.7 HAP EFs for carbon adsorber units at submerged loading operations using dedicated normal service. (FPT site)

HAP	Control Effic.%	Emission Factor by Gasoline Type (EF)[a] (mg-HAP/l gasoline transferred)	
		Normal	Oxygenated
MTBE	100.00	Na	0
Benzene	99.95	0.0027	0.0021
Toluene	99.10	0.0690	0.0584
Ethylbenzene	100	0	0
Xylenes[b]	99.08	0.0270	0.0216
Sum HAPs[c]	99.54	0.0990	0.0821

[a] Calculated using AP-42 uncontrolled VOC emission factor of 590 mg/l and vapor HAP to VOC content listed in Table 4.5

[b] Xylenes calculated using the average CE% of m-xylene and p-xylene

[c] Sum of five HAPs evaluated in this study

The EFs from Table 4.6 and 4.7 used for estimation of the emissions of specific HAP compounds as follows:

$$E_{HAPi} = V_T \times EF_{HAPi}$$

Where : E_{HAPi} = controlled emissions (mg/time period) for HAP_i

EF_{HAPi} = emission factor (mg/liter) for HAP_i

V_T = volume of gasoline transferred (liter/time period)

Volume of Gasoline loaded divided by the type of gasoline as reported by Shell in 2002 i.e. octane No. 91 (normal gasoline) and octane No.95 (oxygenate gasoline) were 240,000,000 liters and 360,000,000 liters, respectively (Sunan Chanfun, interviewed by February 29, 2003). While FPT has reported the volume of gasoline octane No.91 and octane No.95 loaded at 173,049,301 liters and 83,388,026 liters, respectively (Pinit Boonsenan, interviewed by March 3, 2003). Controlled HAPs were calculated by EF_{HAPi} and V_T, shown in Table 4.8. The comparison of uncontrolled emissions and controlled emissions are shown in Table 4.9 and Figure 4.2.

Table 4.8 Estimation of HAP Emission rates for Shell and FPT, (Kg./year)

HAP	Annual emissions at Shell[a]		Annual emissions at FPT[a]	
	Octane 91	Octane 95	Octane 91	Octane 95
MTBE	Na	151.128	Na	0
Benzene	51.864	60.516	0.467	0.175
Toluene	81.936	104.04	11.940	4.870
Ethylbenzene	0	0	0	0
Xylenes[b]	17.280	20.736	4.672	1.801
Total HAPs[c]	151.08	336.42	17.080	6.846
Total VOCs	264.6		27.23	

[a] based on gasoline loaded in year 2002
[b] m-Xylene, p-Xylene were included
[c] HAPs mean MTBE, Benzene, Toluene, Ethylbenzene and Xylenes

Table 4.9 Estimation of uncontrolled emission and controlled emission of Shell Thailand and FPT in year 2002

HAP	Annual emissions at Shell[a]		Annual emissions at FPT[a]	
	Uncontrolled	Controlled	Uncontrolled	Controlled
MTBE	4284	151.13	992.32	0
Benzene	468	112.38	214.12	0.64
Toluene	708	185.98	316.69	16.81
Ethylbenzene	60	0	25.64	0
Xylenes[b]	264	38.02	119.88	6.47
Total HAPs[c]	5784	404.48	1668.65	29.93

[a] based on gasoline loaded in year 2002

[b] m-Xylene, p-Xylene were included

[c] HAPs mean MTBE, Benzene, Toluene, Ethylbenzene and Xylenes

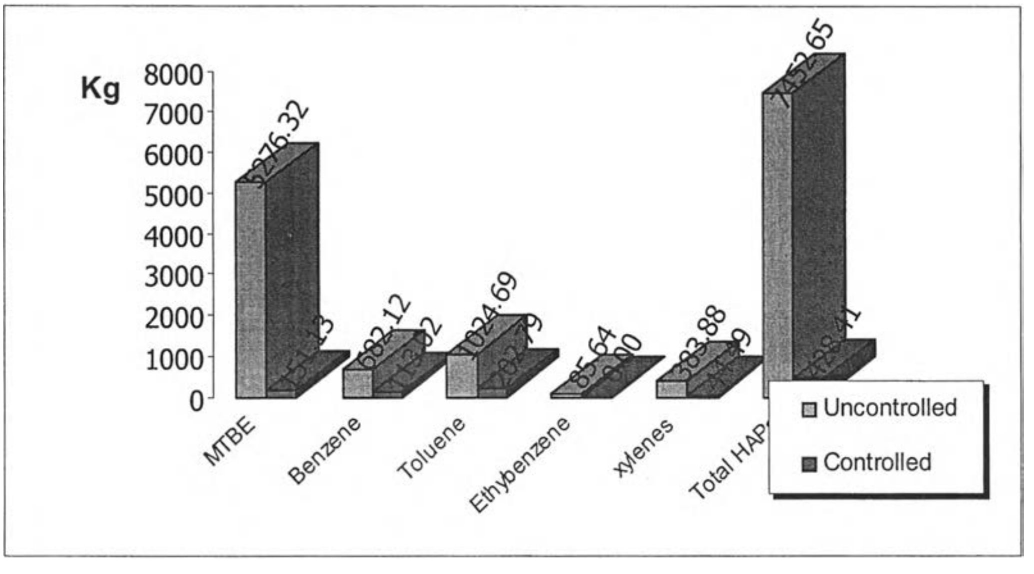

Figure 4.2 : Estimation uncontrolled emissions and controlled emissions (Shell&FPT)

Figure 4.2, show HAPs generated during gasoline loaded from both bulk gasoline terminals i.e. FPT and Shell, was 7,452.65 Kg. MTBE emission was the highest at 5,276.32 Kg. While ethylbenzene was the less emitted by 85.64 Kg. The VRU showed the results of controlling those HAPs more than 99% but the total HAPs after controlled still emitted of 423.41 Kg in year 2002.

The average totally VOCs generated by Shell and FPT in year 2002, were 588,000 kg and 151,298 kg respectively without the vapor control equipment. The implementation of VRU could reduce the VOCs emission to 264 kg,and 27.23 kg at Shell and FPT, respectively.

MTBE has been used for lead replacement as an octane enhancer (helps prevent the engine from "knocking"). Oxygen helps gasoline burn more completely, reducing a harmful tailpipe emissions from motor vehicles especially carbon monoxide. The Connecticut Academy of Science and Engineering (CASE, 1999) reported on the impact of gasoline additive, MTBE adding has been reduced the percentage of toxic air (benzene, ethyl benzene, toluene, xylenes and hexane), known as the human carcinogens. This reduction is accompanied by an increasing in the level of MTBE in the air. Nevertheless, the background information for proposed standard of EPA (1994), delineated that the inclusion of MTBE in the liquid to meet the oxygen demands but it increased the HAP to VOC ratio in gasoline vapor from approximately 5 weight percent to near 16 percent (with the 15 percent MTBE gasoline). Consequently, MTBE was the highest amount of HAPs that emitted from the control device in this study.

MTBE is highly soluble in water and easy to transfer to groundwater from gasoline leaking from underground storage tanks, pipelines and other components of the gasoline distribution system (University of California, Research & Teaching, 1998). Besides, it has been found that there are significant risks and costs associated with water contamination due to the use of MTBE. Therefore, the replacement of MTBE to ethanol has begun in the United States to prevent those problems. On March 15, 2002, the Governor issued a new Executive Order and announced a one-year extension to the phase out of MTBE. "Under the newly announced timeline, the MTBE phase out will be accomplished no later than December 31, 2003 (California Energy Commission, 2003). If MTBE is switched to ethanol in Thailand with same reason as the United States, the HAPs character emitted from gasoline transfer operation will be changed.

4.4 Effect of VOCs controlled to O_3 reduction in Bangkok

The study of Boaning in 2002 found that to reduce O_3 formation in Bangkok, VOCs should be controlled because the sensitivity analysis showed that O_3 formation in Bangkok is more sensitive to VOC than NO_x emissions. The report also stated that to ensure the highest ozone concentration in Bangkok is below the standard of 100 ppb., VOC emissions should be reduced by about 60%.

The air emission sources database in the Bangkok Metropolitan Region 1997 has been shown that the total VOCs emission in Bangkok city was 179,963 tons and will be increased to 212,180 tons in 2002, estimated by Gauss Model of Airvivo system (Table 4.9). The sources of pollutant emissions were classified by sources of pollutants generated, point source (factories), mobile source (vehicle) and area sources (residential, gasoline transfer operations and aviation) and the gasoline transfer operations contributed the most ratio of VOCs generated and classified as area source which was 88.52%. Therefore, to control VOCs at area source the gasoline transfer operation should be the first priority.

The total amount of gasoline loaded at Shell gasoline terminal in 2002 was 600 million liters, that could approximately generated VOCs 588 tons. With the 99.955% efficiency control of VRU at the Shell, it has been recovered VOCs by 576.24 tons that was 6.72% of VOCs generated and classified as area source or 0.27% of total VOCs generated in Bangkok from all sources.

Table 4.10 Pollutant emission rates (t yr^{-1}) for Bangkok in 1997 and 2002

	Source	NOx		VOC	
		1997	2002	1997	2002
Bangkok	Point	6553	5780	382	332
	Mobile	164,737	170,914	171,086	203,276
	Area	6434	6960	8468	8572
Total		177,724	183,654	179,936	212,180

Source :PCD (2000).

It was estimated that 2,732 million liters of gasoline were loaded from major oil companies 5 terminals in Bangkok in 2002 (Department of Energy Business, 2002). VOCs had been generated approximately 2,677 tons during this amount of gasoline was transferred to tank truck at gasoline terminals (calculated using AP-42 uncontrolled VOC emission factor of 980 mg/l). At an assumption of 95% VOCs control efficiency, the lowest control efficiency for the carbon adsorption technique mentioned by Best Available Control Technology (BACT) of EPA, 2544 tons of VOCs will be controlled by approximately. This amount of removal VOCs (Stage I) is 30% of VOCs generated from area source in Bangkok or 1.2% of total VOCs generated in Bangkok.

Even though, VOCs controlled by VRU comparing to the total VOCs generated in Bangkok is a very small ratio, it is shown that VOCs generated from gasoline transfer operation at gasoline terminal can be efficiently controlled, especially for VOCs generated classified as area source. In addition, those emissions that extremely affect the human health whom work in these premises is reduced. Besides, HAPs contained in VOCs such we know mostly carcinogen i.e. benzene and MTBE were eliminated.

To accommodate the VOCs generated during gasoline transfer, law has been enacted to control gasoline vapor at gasoline terminals, oil tank trucks (Stage I) and gasoline station in Bangkok Metropolitan Regions (Stage II). UAM-V model was applied in the study of Boaning in 2002, the results showed that simulated O_3 peak value would reduce by 2.9% for implementing Stage I completion.

4.5 Cost effectiveness of VRU

The cost effectiveness for the emission control from bulk gasoline loading operation is defined as the total annualized cost divided by the total emissions controlled per year (Baht / mg VOC or HAPs controlled). However, the specific or actual information used for calculation was quite limited. Thus, some data used in this study would be estimated based on the existing condition.

The capital investment cost of the vapor recovery system at the Shell Thailand included vapor recovery unit and gasoline loading rack modification. The loading racks were modified from the traditional operation, top loading, to bottom loading. The capital cost of the system at FPT was expended for vapor recovery unit and modification of 2 from 14 loading racks but still used top loading operation.

Annual operating cost included electricity to power compressors, pumps, and blowers, routine maintenance, chemical and operating labor. The unit requires overhaul maintenance every 5 years and it costs around 0.5% of the unit's investment cost. The price of activated carbon is estimated at 4 U.S. Dollar per kilogram, and the activated carbon is assumed to has a working life of 10 years (Fuel Pipeline Transportation, May 2001 and Shell Bangkok Thailand, May 2001). Total activated carbon in the bed of VRU at FPT and Shell are 11,440 kg and 19,740 kg., respectively.

Recovery volume was at 0.12% and 0.08% by volume of liter gasoline loaded at Shell and FPT, respectively The recovered gasoline will be sold as a gasoline regular grade and has to pay tax at 30%. The average price of gasoline for the last 5 years is 13 Baht per liter. It is assumed that gasoline consumption in Bangkok will be increase approximately 1.5% by volume. The full capacity of the vapor recovery unit at FPT and Shell were 1.6 million cubic meter per year and 2.038 million cubic meter per year, respectively (Fuel Pipeline Transportation, May 2001 and Shell Bangkok Thailand, May 2001). Therefore, the unit could be operated in the future year with the increasing rate 1.5% of gasoline loaded. Both of the total VOC and HAPs controlled are the difference between the uncontrolled and the controlled emission level. All data of FPT and Shell are presented in Table 4.10 and 4.11, respectively.

The net present value (NPV) of an average cost per kilogram of VOCs removed (a) is NPV of total cost for 20 years of VRU's life divided by NPV of total VOCs removed by VRU through 20 years. The formula shows as below. Discount rate (r) used in the study is 10%.

$$a = \frac{\Sigma\, Ct/(1+r)^t}{\Sigma\, Qt/(1+r)^t}$$

Where	Ct	= cost at time t
	t	= period time of VRU life
	Qt	= Quantity of emission removed at time t
	r	= discount rate

Table 4.10, cost effectiveness of VRU's FPT, showed that the NPV of average revenue through 20 years is 17.57 million Baht. The NPV of total annual cost for 20 years is 36.23 million Baht and the NPV of total VOCs removed by VRU through 20 years is 1423.37 tons. So, an average cost per kilogram of VOCs removed is 25.45 Baht (36.23 MB/1423.37 tons) while an average revenue per kilogram of VOCs removed is 12.34 Baht (17.57 MB/ 1423.37 tons). Due to the result shown that the net annual revenue through 20 years is shown negative result at -18.66 million Baht, therefore the unit might not make a profit for the company.

Table 4.11, cost effectiveness of VRU's Shell, shows that the NPV of average revenue through 20 years is 61.65 million Baht. The NPV of total annual cost for 20 years is 127.62 million Baht and the NPV of total VOCs removed by VRU through 20 years is 5,530.23 tons. The average cost per kilogram of VOCs removed is 23.08 Baht (127.62 MB/5,530.23 tons) while an average revenue per kilogram of VOCs removed is 11.15 Baht (65.97 MB/ 5,530.23 tons). In the same way of FPT case, the net annual revenue through 20 years is shown negative at -65.97 million Baht, therefore the unit might not make a profit for the company.

Table 4.11 Cost effectiveness of vapor recovery unit (FPT)

Year	Gasoline Loaded 91 (liter/yr)	Gasoline Loaded 95 (liter/yr)	VOCs Generation (kgVOCs/yr)	VOCs Removal (kgVOCs/yr)	HAPs Removal (kgHAPs/yr)	Capital cost (MB)	O&M Cost (MB/yr)	Total Annual Cost (MB/yr)	Gasoline Recovered (lit)	Revenue (MB/yr)	Net annual Revenue (MB/yr)
2002	173,049,301	83,388,026	151,298	151,270.79	1644.72	36.08	0.11898	36.20	205,150	1.867	- 34.33
2003	175,645,041	84,638,846	153,567	153,539.85	1669.39		0.11898	0.12	208,227	1.895	1.78
2004	178,279,716	85,908,429	155,871	155,842.95	1694.43		0.11898	0.12	211,351	1.923	1.80
2005	180,953,912	87,197,056	158,209	158,180.59	1719.85		0.11898	0.12	214,521	1.952	1.83
2006	183,668,221	88,505,011	160,582	160,553.30	1745.65		1.51898	1.52	217,739	1.981	0.46
2007	186,423,244	89,832,587	162,991	162,961.60	1771.83		0.11898	0.12	221,005	2.011	1.89
2008	189,219,593	91,180,075	165,436	165,406.03	1798.41		0.11898	0.12	224,320	2.041	1.92
2009	192,057,886	92,547,776	167,917	167,887.12	1825.39		0.11898	0.12	227,685	2.072	1.95
2010	194,938,755	93,935,993	170,436	170,405.42	1852.77		0.11898	0.12	231,100	2.103	1.98
2011	197,862,836	95,345,033	172,993	172,961.50	1880.56		1.51898	1.52	234,566	2.135	0.62
2012	200,830,779	96,775,208	175,588	175,555.93	1908.77		2.0409	2.04	238,085	2.167	0.13
2013	203,843,240	98,226,837	178,221	178,189.27	1937.40		0.11898	0.12	241,656	2.199	2.08
2014	206,900,889	99,700,239	180,895	180,862.10	1966.46		0.11898	0.12	245,281	2.232	2.11
2015	210,004,402	101,195,743	183,608	183,575.04	1995.96		0.11898	0.12	248,960	2.266	2.15
2016	213,154,468	102,713,679	186,362	186,328.66	2025.89		1.51898	1.52	252,695	2.300	0.78
2017	216,351,785	104,254,384	189,158	189,123.59	2056.28		0.11898	0.12	256,485	2.334	2.22
2018	219,597,062	105,818,200	191,995	191,960.45	2087.13		0.11898	0.12	260,332	2.369	2.25
2019	222,891,018	107,405,473	194,875	194,839.85	2118.43		0.11898	0.12	264,237	2.405	2.29
2020	226,234,383	109,016,555	197,798	197,762.45	2150.21		0.11898	0.12	268,201	2.441	2.32
2021	229,627,899	110,651,803	200,765	200,728.89	2182.46		0.11898	0.12	272,224	2.477	2.36
		NPV	ton	*1,423.37*				*฿36.23*	*1,930,336*	*฿17.57*	*-฿18.66*

Table 4.12 Cost effectiveness of vapor recovery unit (Shell)

Year	Gasoline Loaded 91 (liter/yr)	Gasoline Loaded 95 (liter/yr)	VOCs Generation (kgVOCs/yr)	VOCs Removal (kgVOCs/yr)	HAPs Removal (kgHAPs/yr)	Capital cost (MB)	O&M Cost (MB/yr)	Total Annual Cost (MB/yr)	Gasoline recovered (Lit)	Revenue (MB/yr)	Net annual Revenue (MB/yr)
2002	240,000,000	360,000,000	588,000	587,735.40	5296.51	118.0	2.05	120.05	720,000	6.552	- 113.50
2003	243,600,000	365,400,000	596,820	596,551.43	5375.96		2.05	2.05	730,800	6.650	4.60
2004	247,254,000	370,881,000	605,772	605,499.70	5456.60		2.05	2.05	741,762	6.750	4.70
2005	250,962,810	376,444,215	614,859	614,582.20	5538.45		2.05	2.05	752,888	6.851	4.80
2006	254,727,252	382,090,878	624,082	623,800.93	5621.53		3.55	3.55	764,182	6.954	3.40
2007	258,548,161	387,822,241	633,443	633,157.94	5705.85		2.05	2.05	775,644	7.058	5.01
2008	262,426,383	393,639,575	642,945	642,655.31	5791.44		2.05	2.05	787,279	7.164	5.11
2009	266,362,779	399,544,169	652,589	652,295.14	5878.31		2.05	2.05	799,088	7.272	5.22
2010	270,358,221	405,537,331	662,378	662,079.57	5966.48		2.05	2.05	811,075	7.381	5.33
2011	274,413,594	411,620,391	672,313	672,010.76	6055.98		3.55	3.55	823,241	7.491	3.94
2012	278,529,798	417,794,697	682,398	682,090.93	6146.82		5.13632	5.14	835,589	7.604	2.47
2013	282,707,745	424,061,617	692,634	692,322.29	6239.02		2.05	2.05	848,123	7.718	5.67
2014	286,948,361	430,422,542	703,023	702,707.12	6332.61		2.05	2.05	860,845	7.834	5.78
2015	291,252,587	436,878,880	713,569	713,247.73	6427.60		2.05	2.05	873,758	7.951	5.90
2016	295,621,375	443,432,063	724,272	723,946.45	6524.01		3.32	3.32	886,864	8.070	4.75
2017	300,055,696	450,083,544	735,136	734,805.64	6621.87		2.05	2.05	900,167	8.192	6.14
2018	304,556,531	456,834,797	746,164	745,827.73	6721.20		2.05	2.05	913,670	8.314	6.26
2019	309,124,879	463,687,319	757,356	757,015.14	6822.02		2.05	2.05	927,375	8.439	6.39
2020	313,761,753	470,642,629	768,716	768,370.37	6924.35		2.05	2.05	941,285	8.566	6.52
2021	318,468,179	477,702,268	780,247	779,895.93	7028.21		2.05	2.05	955,405	8.694	6.64
		NPV	ton	5,530.23				฿127.62	6,774,764	฿61.65	-฿65.97

The conclusion of cost effectiveness of VRU is presented in Table 4.12.

Table 4.13 The conclusion of cost effectiveness of VRU

	Shell (Baht)	FPT (Baht)
Net annual revenue of VRU	-65.97 million Baht	-18.66 million Baht
Average cost per kg. of VOCs removed	23.08	25.45
Average revenue per kg of VOCs removed	11.15	12.34

From the Table 4.12, even though the net annual revenue of Shell of Thailand is higher than FPT, it still shows that an average cost per kilogram of VOCs removed in lower than FPT. So it could imply that the quantity of gasoline loaded affects the cost per liter of gasoline transferred. The more gasoline transferred from the terminal with pass through the VRU the less cost pay to remove those emissions.

The study of cost effectiveness as mentioned above was based on the current situation. It was found that implementing VRU with the partial unit utilization, gasoline throughput is under design, can cause the company a financial burden. Therefore, a study of cost effectiveness with a full capacity (1.6 million cubic meter and 2.038 million cubic meter of FPT and Shell, respectively) of the unit under the same conditions as the previous study shows the different cost effectiveness of VRU as shown in the Table 4.14 and 4.15 for FPT and Shell, respectively.

The cost effectiveness of the unit at FPT shows that under the full utilization of VRU, the NPV of average revenue through 20 years is 56.55 million Baht and the NPV of total VOCs removed by VRU through 20 years is 4582.34 tons. So, an average cost per kilogram of VOCs removed is 7.9 Baht (36.23 MB/4582.34 tons) while an average revenue per kilogram of VOCs removed is 12.34 Baht (56.55 MB/ 4582.34 tons). The net annual revenue through 20 years is shown positive result at 20.32 million Baht, therefore the company can get a profit from this control device.

Table 4.14 Cost effectiveness of vapor recovery unit with full capacity operation (FPT)

Year	Gasoline Loaded		VOCs Generation (kgVOCs/yr)	VOCs Removal (kgVOCs/yr)	Capital cost (MB)	O&M Cost (MB/yr)	Total Annual Cost (MB/yr)	Gasoline Recovered (lit)	Revenue (MB/yr)	Net annual Revenue (MB/yr)
	91 (liter/yr)	95 (liter/yr)								
2002	173,049,301	83,388,026	151,298	151,270.79	36.08	0.11898	36.20	205,150	1.867	- 34.33
2003	212,089,223	102,200,365	185,431	185,397.48		0.11898	0.12	251,432	2.288	2.17
2004	259,936,552	125,256,767	227,264	227,223.15		0.11898	0.12	308,155	2.804	2.69
2005	318,578,238	153,514,694	278,535	278,484.69		0.11898	0.12	377,674	3.437	3.32
2006	390,449,489	188,147,608	341,372	341,310.84		1.51898	1.52	462,878	4.212	2.69
2007	478,534,893	230,593,709	418,386	418,310.57		0.11898	0.12	567,303	5.162	5.04
2008	586,492,365	282,615,650	512,774	512,681.43		0.11898	0.12	695,286	6.327	6.21
2009	718,805,043	346,373,740	628,455	628,342.36		0.11898	0.12	852,143	7.755	7.64
2010	880,967,461	424,515,656	770,235	770,096.40		0.11898	0.12	1,044,386	9.504	9.38
2011	1,079,713,720	520,286,388	944,000	943,830.14		1.51898	1.52	1,280,000	11.648	10.13
2012	1,079,713,720	520,286,388	944,000	943,830.14		2.0409	2.04	1,280,000	11.648	9.61
2013	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
2014	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
2015	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
2016	1,079,713,720	520,286,388	944,000	943,830.14		1.51898	1.52	1,280,000	11.648	10.13
2017	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
2018	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
2019	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
2020	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
2021	1,079,713,720	520,286,388	944,000	943,830.14		0.11898	0.12	1,280,000	11.648	11.53
		NPV	ton	*4,582.34*			*฿36.23*	*6,214,467*	*฿56.55*	*฿20.32*

Table 4.15 Cost effectiveness of vapor recovery unit with full capacity operation (Shell)

Year	Gasoline Loaded 91 (liter/yr)	Gasoline Loaded 95 (liter/yr)	VOCs Generation (kgVOCs/yr)	VOCs Removal (kgVOCs/yr)	Capital cost (MB)	O&M Cost (MB/yr)	Total Annual Cost (MB/yr)	Gasoline recovered (Lit)	Revenue (MB/yr)	Net annual Revenue (MB/yr)
2002	240,000,000	360,000,000	588,000	587,735.40	118.0	2.05	120.05	720,000	6.552	- 113.50
2003	274,920,000	412,380,000	673,554	673,250.90		2.05	2.05	824,760	7.505	5.46
2004	314,920,860	472,381,290	771,556	771,208.91		2.05	2.05	944,763	8.597	6.55
2005	360,741,845	541,112,768	883,818	883,419.80		2.05	2.05	1,082,226	9.848	7.80
2006	413,229,784	619,844,675	1,012,413	1,011,957.38		3.55	3.55	1,239,689	11.281	7.73
2007	473,354,717	710,032,076	1,159,719	1,159,197.18		2.05	2.05	1,420,064	12.923	10.87
2008	542,227,828	813,341,743	1,328,458	1,327,860.37		2.05	2.05	1,626,683	14.803	12.75
2009	621,121,977	931,682,966	1,521,749	1,521,064.06		2.05	2.05	1,863,366	16.957	14.91
2010	711,495,225	1,067,242,838	1,743,163	1,742,378.88		2.05	2.05	2,134,486	19.424	17.37
2011	815,017,780	1,222,526,671	1,996,794	1,995,895.01		3.55	3.55	2,445,053	22.250	18.70
2012	815,017,780	1,222,526,671	1,996,794	1,995,895.00		5.13632	5.14	2,445,053	22.250	17.11
2013	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
2014	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
2015	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
2016	815,017,780	1,222,526,671	1,996,794	1,995,895.00		3.32	3.32	2,445,053	22.250	18.93
2017	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
2018	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
2019	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
2020	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
2021	815,017,780	1,222,526,671	1,996,794	1,995,895.00		2.05	2.05	2,445,053	22.250	20.20
		NPV	ton	*11,183.90*			*฿127.62*	*13,700,740*	*฿124.68*	*-฿2.94*

At the full utilization of VRU at Shell, it is found that the NPV of average revenue through 20 years is 124.68 million Baht and the NPV of total VOCs removed by VRU through 20 years is 11,183.9 tons. Therefore, an average cost per kilogram of VOCs removed is 11.41 Baht (127.62 MB/11,183.90 tons) while an average revenue per kilogram of VOCs removed is 11.15 Baht (124.68 MB/ 11,183.9 tons). The net annual revenue through 20 years is shown a negative result at -2.94 million Baht, therefore the company can get a profit from this control device.

The conclusion of cost effectiveness of VRU with full utilization is presented in Table 4.16.

Table 4.16 The conclusion of cost effectiveness of VRU with full utilization

	Shell (Baht)	FPT (Baht)
Net annual revenue of VRU	-2.94 million Baht	20.32 million Baht
Average cost per kg. of VOCs removed	11.41	7.90
Average revenue per kg of VOCs removed	11.15	12.34

To consider a pay back period of the unit investment with full utilization (Table 4.14 and 4.15), it is found that FPT and Shell will get the profit from the VRU in the ninth year and eleventh year, respectively as shown in the Table 4.17.

The results of cost effectiveness in this study well agreed with the results of EPA's studies (Table 4.18). The trial study of bulk terminal loading rack cost, for control VOC at 10 mg per liter gasoline loaded, was performed with 4 different level of gasoline throughput with three techniques for control emission, Carbon adsorption, Thermal Oxidizer and Refrigeration. The table indicates that employing carbon adsorption unit to control VOCs could gain when gasoline throughput is increased. It imply that the more gasoline loaded at terminal the cost of VOCs controlled will be decrease. (U.S.EPA, Office of Air Quality Planning and Standards, 1994s).

Table 4.17 Pay back period of VRU investment at FPT and Shell (Million Baht)

Year	Shell	FPT	Year	Shell	FPT
1	-113.50	-34.33	11	5.75	24.54
2	-108.04	-32.16	12	25.95	36.07
3	-101.50	-29.47	13	46.15	47.60
4	-93.70	-26.16	14	66.35	59.13
5	-85.97	-23.46	15	85.28	69.26
6	-75.09	-18.42	16	105.48	80.79
7	-62.34	-12.21	17	125.68	92.32
8	-47.43	-4.58	18	145.88	103.85
9	-30.06	4.81	19	166.08	115.38
10	-11.36	14.94	20	186.28	126.91

However, all above discussed are only on monetary view. There are other benefits that could get from the emissions control at gasoline terminals by VRU i.e. reducing toxic substance such as benzene and MTBE known as a carcinogen. Therefore, it could reduce the risk of health impact to operators whom work at site during gasoline loaded. Nevertheless, the health benefit from VOCs and HAPs reduction at gasoline terminals can theoretically be valued from the reduction of sickness day-off of operators who work at site (Figure 4.3). The explanation this value, Figure 4.3 shown that when the VOCs was reduced (A_{VOC} to B_{VOC}), the occurrence of sickness of operators will be reduced. The difference of occurrence of sickness from level A_S (VOCs concentration at A) and level B_S (VOCs concentration at B) are the health benefit that could be valued. This value getting from the reduction of VOCs and HAPs by VRU should be more studied to obtain the information of health benefit. At the time of writing, such an empirical study is not available to the researcher. So, this value is not estimated for the present study.

The study of Air & Waste Technology in 1995 stated that 85% of gasoline station (17 out of 20) owner expressed concerned on the health impacts to the gas station attendants. Besides, they agreed with the idea of vapor recovery control. The other major profit getting from emission reduction was reducing of ozone formation that is a major air pollution problem in Bangkok as mentioned in 4.4.

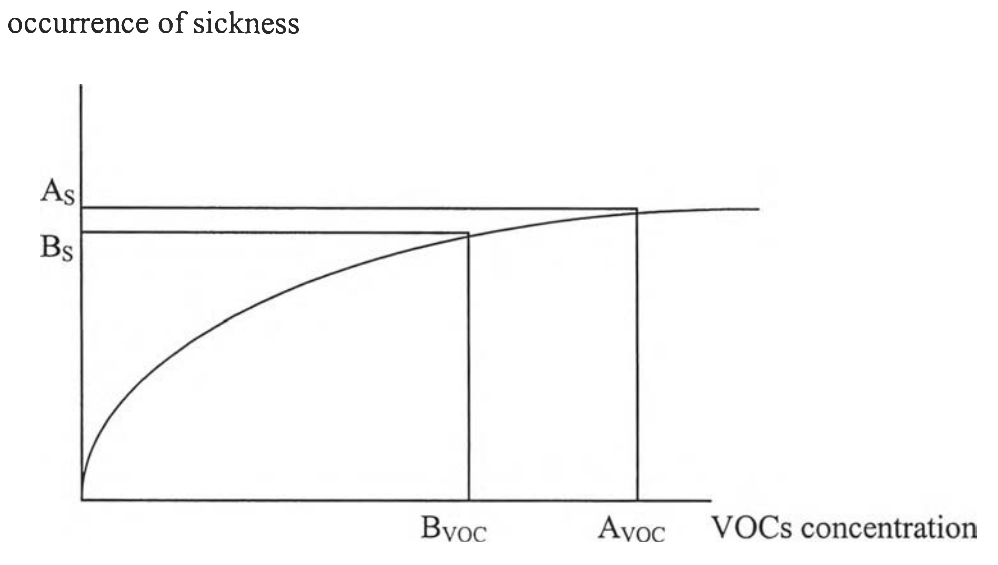

Figure 4.3 Health benefit from VOCs reduction

In conclusion, even though the vapor recovery system will cause the company a financial burden, it will benefit far better from both reduced chance of the gasoline loading terminal personnel to expose the hazardous air pollutants and reduced level of air pollution, especially for ozone accumulation.

Table 4.18 Bulk terminal loading rack costs – New 10mg/ l Unit (Thousand of third quarter 1990 Dollars)

Gasoline throughput	380,000 l/day			950,000 l/day			1,900,000 l/day			3,800,000 l/day		
Vapor Processor	CA	TO	REF	CA	TO	REF	CA	TO	REF	CA	TO	REF
Capital Investment												
Unit purchase cost	237.9	108	318	245.9	119	387	254.8	119	387	297.4	137	462
Unit installation cost	202.2	92	270.3	209	101	329	216.6	101	329	252.8	116	392.7
Annual Operating Costs												
Electricity	9	1	4.3	12	6	10.8	16	8	21.6	25	18	43.2
Pilot gas		7.3			16.7			33			61.6	
Carbon replacement	2.1			2.9			3.8			5.2		
Maintenance	6	3.5	11.6	6	3.5	11.6	6	3.5	11.6	6	3.5	11.6
Operating Labor	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Subtotal (Direct Operating Cost)	23.9	18.6	22.7	22.7	33	29.2	32.6	51.3	40	43	89.9	61.6
Capital charges (16.3%)	71.7	32.5	95.9	74.2	35.9	116.7	76.8	35.9	116.7	89.7	41.2	139.3
Tax and Insurance (4%)	17.6	8	23.5	18.2	8.8	28.6	18.9	8.8	28.6	22	10.1	34.2
Net Annualized Cost	55.8	59.1	84.7	(23.5)	77.8	31	(158.9)	96	(101.8)	(419.6)	141.2	(339.2)
Total VOC Controlled, Mg VOC/yr	132.7	132.7	132.7	331.7	331.7	331.7	663.4	663.4	663.4	1326.9	1326.9	1326.9
Cost Effectiveness, \$/Mg VOC	420	445	638	(71)	235	93	(240)	145	(153)	(316)	106	(256)

Source: USEPA, Office of Air Quality Planning and Standards , 1994