Table 2-13(1) The Results of the Estimation for Each Index Element by the CMB Method (1st Survey)

MS 1

Element		Calculated (ng/m^3)	Observed (ng/m^3)	Calculated / Observed	
Index elements	Al	1544.680	1300.000	1.19	
	Br	80.356	42.000	1.91	+
	Ca	237.305	2100.000	0.11	---
	Cr	8.933	6.500	1.37	
	Fe	784.282	1700.000	0.46	--
	K	914.378	1300.000	0.70	
	Mn	51.488	60.000	0.86	
	Na	1116.683	1100.000	1.02	
	Ni	9.869	19.000	0.52	-
	Pb	473.892	450.000	1.05	
	Sb	0.296	29.000	0.01	---
	Sc	0.123	0.200	0.62	-
	Se	0.445	0.450	0.99	
	Ti	74.809	67.000	1.12	
	V	12.375	12.000	1.03	
	Zn	71.802	720.000	0.10	---
	C_{ele}	15631.883	15300.000	1.02	
	C_{org}	3353.184	8700.000	0.39	--
Total		24366.783	32906.150	0.74	

MS 2

Element		Calculated (ng/m^3)	Observed (ng/m^3)	Calculated / Observed	
Index elements	Al	989.046	810.000	1.22	
	Br	32.761	17.000	1.93	+
	Ca	246.933	1200.000	0.21	---
	Cr	9.651	7.300	1.32	
	Fe	709.371	1300.000	0.55	-
	K	619.898	1100.000	0.56	-
	Mn	52.987	58.000	0.91	
	Na	1724.819	1700.000	1.01	
	Ni	11.563	10.000	1.16	
	Pb	165.451	1590.000	0.10	---
	Sb	0.335	64.000	0.01	---
	Sc	0.078	0.130	0.60	-
	Se	0.379	0.500	0.76	
	Ti	47.990	86.000	0.56	-
	V	14.903	16.000	0.93	
	Zn	72.119	960.000	0.08	---
	C_{ele}	13877.363	13500.000	1.03	
	C_{org}	2513.216	5800.000	0.43	--
Total		21088.866	28218.930	0.75	

MS 3

Element		Calculated (ng/m^3)	Observed (ng/m^3)	Calculated / Observed	
Index elements	Al	1321.682	1100.000	1.20	
	Br	68.544	31.000	2.21	++
	Ca	627.745	2600.000	0.24	---
	Cr	46.547	31.000	1.50	+
	Fe	3021.493	4700.000	0.64	-
	K	807.878	1700.000	0.48	--
	Mn	267.251	360.000	0.74	
	Na	1412.067	1400.000	1.01	
	Ni	40.191	47.000	0.86	
	Pb	494.477	780.000	0.63	-
	Sb	2.380	17.000	0.14	---
	Sc	0.104	0.190	0.54	-
	Se	1.318	1.000	1.32	
	Ti	65.672	130.000	0.51	-
	V	34.743	35.000	0.99	
	Zn	302.729	3700.000	0.08	---
	C_{ele}	16729.996	16400.000	1.02	
	C_{org}	3530.656	10800.000	0.33	--
Total		28775.471	43332.190	0.66	

MS 4

Element		Calculated (ng/m^3)	Observed (ng/m^3)	Calculated / Observed	
Index elements	Al	1629.855	1400.000	1.16	
	Br	57.342	37.000	1.55	+
	Ca	244.567	1600.000	0.15	---
	Cr	6.896	5.100	1.35	
	Fe	730.138	1700.000	0.43	--
	K	975.355	1200.000	0.81	
	Mn	44.904	75.000	0.60	-
	Na	1529.263	1500.000	1.02	
	Ni	5.154	5.000	1.03	
	Pb	313.569	290.000	1.08	
	Sb	-0.034	17.000	0.00	---
	Sc	0.130	0.200	0.65	-
	Se	0.331	0.400	0.83	
	Ti	78.824	140.000	0.56	-
	V	7.138	7.400	0.96	
	Zn	60.046	760.000	0.08	---
	C_{ele}	16574.312	16200.000	1.02	
	C_{org}	3238.669	9400.000	0.34	--
Total		25496.466	34337.100	0.74	

MS 5

Element		Calculated (ng/m^3)	Observed (ng/m^3)	Calculated / Observed	
Index elements	Al	2643.747	2200.000	1.20	
	Br	7.638	18.000	0.42	--
	Ca	184.978	2100.000	0.09	---
	Cr	4.520	3.300	1.37	
	Fe	638.449	1100.000	0.58	-
	K	1532.589	2000.000	0.77	
	Mn	26.295	41.000	0.64	-
	Na	1158.068	1100.000	1.05	
	Ni	5.642	4.000	1.41	
	Pb	31.873	30.000	1.06	
	Sb	0.625	5.400	0.12	---
	Sc	0.212	0.230	0.92	
	Se	0.694	0.960	0.72	
	Ti	128.762	150.000	0.86	
	V	4.391	5.000	0.88	
	Zn	35.547	140.000	0.25	--
	C_{ele}	9761.973	9500.000	1.03	
	C_{org}	1603.416	5700.000	0.28	--
Total		17769.418	24097.890	0.74	

(Calculated/Observed)

≧4.0	------->	+++
≧2.0	------->	++
≧1.5	------->	+
≦0.7	------->	-
≦0.5	------->	--
≦0.25	------->	---

Table 2-13(2) The Results of the Estimation for Each Index Element by the CMB Method (2nd Survey)

MS 1

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	870.342	760.000	1.15
	Br	14.653	14.000	1.05
	Ca	160.346	730.000	0.22 ---
	Cr	5.053	3.700	1.37
	Fe	414.016	700.000	0.59 -
	K	544.630	640.000	0.85
	Mn	27.879	50.000	0.56 -
	Na	1478.572	1400.000	1.06
	Ni	5.204	3.500	1.49
	Pb	53.560	50.000	1.07
	Sb	0.331	5.100	0.06 ---
	Sc	0.069	0.110	0.63 -
	Se	0.309	1.100	0.28 --
	Ti	42.388	97.000	0.44 --
	V	5.161	6.400	0.81
	Zn	39.029	250.000	0.16 ---
	C_{ele}	7699.875	7500.000	1.03
	C_{org}	1321.108	4300.000	0.31 --
Total		12682.525	16510.910	0.77

MS 2

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	341.211	310.000	1.10
	Br	14.990	9.000	1.67 +
	Ca	198.370	400.000	0.50 --
	Cr	7.272	10.000	0.73
	Fe	147.035	420.000	0.35 --
	K	294.885	350.000	0.84
	Mn	14.159	11.000	1.29
	Na	2849.898	2800.000	1.02
	Ni	21.145	19.000	1.11
	Pb	19.870	20.000	0.99
	Sb	1.453	1.400	1.04
	Sc	0.026	0.054	0.49 --
	Se	0.677	51.000	0.01 ---
	Ti	17.190	98.000	0.18 ---
	V	25.624	26.000	0.99
	Zn	50.477	82.000	0.62 -
	C_{ele}	7730.535	7500.000	1.03
	C_{org}	1167.984	4000.000	0.29 --
Total		12902.802	16107.454	0.80

MS 3

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	574.714	490.000	1.17
	Br	43.551	19.000	2.29 ++
	Ca	241.465	2000.000	0.12 ---
	Cr	16.745	10.000	1.67 +
	Fe	206.005	2000.000	0.10 ---
	K	405.469	1300.000	0.31 --
	Mn	24.943	200.000	0.12 ---
	Na	2140.176	2100.000	1.02
	Ni	50.376	55.000	0.92
	Pb	269.834	380.000	0.71
	Sb	4.019	6.500	0.62 -
	Sc	0.044	0.078	0.57 -
	Se	1.739	1.500	1.16
	Ti	29.741	57.000	0.52 -
	V	56.861	63.000	0.90
	Zn	113.893	2900.000	0.04 ---
	C_{ele}	11797.414	11500.000	1.03
	C_{org}	2087.456	5300.000	0.39 --
Total		18064.446	28382.078	0.64

MS 4

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	780.470	650.000	1.20
	Br	15.426	11.000	1.40
	Ca	183.194	1600.000	0.11 ---
	Cr	4.882	2.900	1.68 +
	Fe	216.116	400.000	0.54 -
	K	514.601	750.000	0.69 -
	Mn	14.299	24.000	0.60 -
	Na	1990.674	1900.000	1.05
	Ni	7.353	6.000	1.23
	Pb	50.517	50.000	1.01
	Sb	1.054	1.700	0.62 -
	Sc	0.062	0.076	0.82
	Se	0.577	0.500	1.15
	Ti	38.356	50.000	0.77
	V	4.226	4.500	0.94
	Zn	47.794	100.000	0.48 --
	C_{ele}	11819.266	11500.000	1.03
	C_{org}	1923.789	5800.000	0.33 --
Total		17612.656	22850.676	0.77

MS 5

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	689.247	570.000	1.21
	Br	11.255	12.000	0.94
	Ca	127.844	250.000	0.51 -
	Cr	1.153	0.770	1.50
	Fe	94.450	260.000	0.36 --
	K	461.546	540.000	0.85
	Mn	1.432	15.000	0.10 ---
	Na	2010.291	1800.000	1.12
	Ni	2.709	3.000	0.90
	Pb	5.032	5.000	1.01
	Sb	0.387	0.470	0.82
	Sc	0.055	0.071	0.78
	Se	0.282	0.950	0.30 --
	Ti	33.615	82.000	0.41 --
	V	2.036	2.100	0.97
	Zn	15.130	18.000	0.84
	C_{ele}	6338.141	6200.000	1.02
	C_{org}	1001.278	4100.000	0.24 ---
Total		10795.883	13859.361	0.78

(Calculated/Observed)
≧4.0 ------> +++
≧2.0 ------> ++
≧1.5 ------> +
≦0.7 ------> -
≦0.5 ------> --
≦0.25 ------> ---

Table 2-13(3) The Results of the Estimation for Each Index Element by the CMB Method (3rd Survey)

MS 1

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	713.921	770.000	0.93
	Br	37.488	26.000	1.44
	Ca	187.702	1700.000	0.11 ---
	Cr	9.499	7.900	1.20
	Fe	648.470	1200.000	0.54 -
	K	433.545	400.000	1.08
	Mn	52.119	71.000	0.73
	Na	760.479	780.000	0.97
	Ni	8.221	5.000	1.64 +
	Pb	231.136	220.000	1.05
	Sb	0.594	5.600	0.11 ---
	Sc	0.057	0.150	0.38 --
	Se	0.406	1.700	0.24 ---
	Ti	34.856	62.000	0.56 -
	V	6.675	8.700	0.77
	Zn	72.637	960.000	0.08 ---
	C_{ele}	10795.746	10600.000	1.02
	C_{org}	2128.732	2700.000	0.79
Total		16122.284	19518.050	0.83

MS 2

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	466.560	410.000	1.14
	Br	7.012	4.500	1.56 +
	Ca	135.547	800.000	0.17 ---
	Cr	7.862	7.900	1.00
	Fe	340.066	840.000	0.40 --
	K	299.957	1400.000	0.21 ---
	Mn	29.501	23.000	1.28
	Na	969.502	1000.000	0.97
	Ni	13.747	22.000	0.62 -
	Pb	40.539	1100.000	0.04 ---
	Sb	1.186	32.000	0.04 ---
	Sc	0.037	0.110	0.33 --
	Se	0.572	0.500	1.14
	Ti	23.277	20.000	1.16
	V	13.359	13.000	1.03
	Zn	54.779	370.000	0.15 ---
	C_{ele}	5571.926	5500.000	1.03
	C_{org}	912.733	2000.000	0.46 --
Total		8988.162	13543.010	0.66

MS 3

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	480.188	410.000	1.17
	Br	20.840	9.500	2.19 ++
	Ca	180.013	1300.000	0.14 ---
	Cr	10.874	7.300	1.49
	Fe	625.162	1700.000	0.37 --
	K	300.474	1100.000	0.27 --
	Mn	52.936	72.000	0.74
	Na	823.559	840.000	0.98
	Ni	16.849	18.000	0.94
	Pb	129.565	230.000	0.56 -
	Sb	0.699	10.000	0.07 ---
	Sc	0.038	0.100	0.38 --
	Se	0.424	0.400	1.06
	Ti	23.555	66.000	0.36 --
	V	21.214	22.000	0.96
	Zn	71.855	1100.000	0.07 ---
	C_{ele}	8314.117	8100.000	1.03
	C_{org}	1528.801	3200.000	0.48 --
Total		12601.161	18185.300	0.69

MS 4

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	716.630	820.000	0.87
	Br	25.460	15.000	1.70 +
	Ca	156.055	1500.000	0.10 ---
	Cr	5.950	4.500	1.32
	Fe	405.389	940.000	0.43 --
	K	442.915	400.000	1.11
	Mn	29.717	34.000	0.87
	Na	1022.368	1100.000	0.93
	Ni	6.390	5.000	1.28
	Pb	140.459	140.000	1.00
	Sb	0.507	4.100	0.12 ---
	Sc	0.057	0.140	0.41 --
	Se	0.361	0.350	1.03
	Ti	34.938	59.000	0.59 -
	V	5.699	6.300	0.90
	Zn	49.285	370.000	0.13 ---
	C_{ele}	9962.352	9700.000	1.03
	C_{org}	1827.459	4000.000	0.46 --
Total		14831.991	19098.390	0.78

MS 5

Element		Calculated (n g/m³)	Observed (n g/m³)	Calculated / Observed
Index elements	Al	723.439	740.000	0.98
	Br	7.945	7.200	1.10
	Ca	112.521	1300.000	0.09 ---
	Cr	5.590	5.000	1.12
	Fe	344.264	450.000	0.77
	K	439.167	450.000	0.98
	Mn	25.428	21.000	1.21
	Na	791.229	790.000	1.00
	Ni	6.493	15.000	0.43 --
	Pb	44.405	40.000	1.11
	Sb	0.845	3.100	0.27 --
	Sc	0.058	0.150	0.38 --
	Se	0.459	0.300	1.53 +
	Ti	35.642	51.000	0.70 -
	V	3.398	3.400	1.00
	Zn	40.651	160.000	0.25 --
	C_{ele}	4105.918	4000.000	1.03
	C_{org}	698.811	2000.000	0.35 --
Total		7386.262	10036.150	0.74

(Calculated/Observed)
- ≧4.0 ------> +++
- ≧2.0 ------> ++
- ≧1.5 ------> +
- ≦0.7 ------> -
- ≦0.5 ------> --
- ≦0.25 ------> ---

(6) The results of the estimate by the CMB method in consideration of the secondary particle

Table 2-14 shows the production of the particulate matter (the diameter is less than 5 μm) on earth—classified into natural products and artificial products—estimated by Ellsaesser[37]. Though the estimate is never accurate, it can be regarded as one of the criteria; the natural products are 69% of all particle matter and the secondary particles are 45%.

Table 2-14 The Production of the Particulate Matter on Earth

		The production of particulate matter: diameter is less than 5 μm (unit: 10^6 ton/yr)	
		Natural products	Artificial products
Primary partcle			
Sea salt		500	—
Soil		100	150*
Forest fire		5	60*
Volcano		25	—
Factory, Plant, Incinerator, etc.		—	30
Sub total	870 (100%)	630 (72%)	240 (28%)
Secondary particle			
Sulphide		335	200
Nitride		60	35
Hydrocarbon		75	15
Sub total	720 (100%)	470 (65%)	250 (35%)
Total	1590 (100%)	1100 (69%)	490 (31%)

*attending on the artificial actions indirectly

The secondary particle is a general term for the particulate matter changed from the emitted gas through chemical chain reactions. Some examples of emitted gas are sulfur compounds (SO_2 and H_2S, etc.), nitrogen compounds (NO_x and NH_3, etc.) and vegetable hydrocarbon (terpen, etc.).

In the following estimate, it is assumed that most of the secondary particles are nitrate and sulphate and that NO_3^- and SO_4^{2-} exist as ammonium salts. Further it is necessary for the estimate of the sulphate ion in the secondary particle to subtract the sulphate ion that originated in Sea salt (primary particle) from the total sulphate iron.

Then S, the concentration in Sea salt $[S_{sea}]$ is estimated with sea salt concentration based on the report by Mizobata[25] that indicates S is 2.6% in sea salt. So the contribution concentrations of the secondary particles are estimated with the following equation:

$$\text{The secondary particle concentration} = \left\{[SO_4^{2-}] - [S_{sea}] \times \frac{96}{32}\right\} \times \frac{132}{96} + [NO_3^-] \times \frac{80}{62} \quad \cdots\cdots\cdots\cdots (2\text{-}21)$$

$[NO_3^-]$: NO_3^- concentration on particulate matter measured by Low-volume sampler

$[SO_4^{2-}]$: SO_4^{2-} concentration on particulate matter measured by Low-volume sampler

Table 2-15 shows the contribution rates of the secondary particle added to the contribution rates on particulate matter estimated by the CMB method with 7 emission sources (Table 2-12).

Table 2-15 The Results of the Estimation by the CMB Method in Consideration of the Secondary Particle

【First survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	4.5	8.9	4.5	6.5	4.4
Soil + Road dust	41.0	29.3	23.8	43.1	76.2
Diesel automobile	34.8	36.8	28.5	37.8	24.5
Gasoline automobile	5.6	1.9	3.5	3.6	0.1
Iron and steel Ind.	2.1	2.7	10.7	1.8	0.3
Fuel oil combustion	0.4	0.6	0.9	0.2	0.1
Glass Industry	0.1	0.1	1.0	-0.2	0.5
Sub total	88.6	80.4	72.9	92.9	106.2
Secondary	12.5	19.1	16.1	14.7	10.4
Total	101.1	99.5	89.0	107.6	116.6

【Second survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	12.2	22.6	10.7	15.8	21.3
Soil + Road dust	41.6	13.7	14.8	35.1	41.7
Diesel automobile	32.7	29.0	27.0	47.6	33.9
Gasoline automobile	0.8	-0.4	2.4	0.4	-0.2
Iron and steel Ind.	2.0	0.4	0.1	0.3	-0.7
Fuel oil combustion	0.3	1.6	2.4	0.2	0.1
Glass industry	0.4	2.0	3.7	1.4	0.7
Sub total	89.8	68.9	61.1	100.9	96.9
Secondary	14.0	24.9	16.9	15.7	11.1
Total	103.8	93.8	78.0	116.6	108.0

【Third survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	5.0	9.7	5.7	7.4	8.4
Soil + Road dust	28.3	26.2	18.7	30.5	47.1
Diesel automobile	38.0	28.7	29.8	37.6	23.1
Gasoline automobile	3.8	0.1	1.9	2.4	0.5
Iron and steel Ind.	3.8	2.6	4.0	2.0	2.3
Fuel oil combustion	0.3	1.1	1.3	0.3	0.2
Glass industry	0.5	2.1	0.7	0.6	1.6
Sub total	79.8	70.4	62.1	80.7	83.3
Secondary	11.5	25.9	20.3	11.1	10.8
Total	91.3	96.3	82.4	91.8	94.1

The result indicates that the total contribution rates are over 100% at some monitoring stations. This is because all SO_4^{2-} and NO_3^- on the particulate matter are regarded as secondary particles (ammonium salts). In addition, the results that the total contribution rates are under 100% at some stations may be due to production by unknown emission sources (most of it may due to slash and burn agriculture).

2.2.4 Consideration

The contribution rates of each emission source type—Sea salt, Soil+Road dust, Diesel automobile, Gasoline automobile, Iron and steel industry, Fuel oil combustion and Glass industry—on particulate matter are estimated by the CMB method (shown in Table 2-12), and the results of this estimate are considered as follows:

(1) Sea salt

The contribution rates of Sea salt are high at some monitoring stations: MS2, MS3 and MS4. This may be because these stations at near the Chao Phraya River (shown in Fig. 2-3). In addition, the contribution rates at MS2 are higher than others. This may be because MS2 is located on the leeward of the river, while the stream direction and wind direction are parallel at MS3 and MS4. With regard to the seasonal change, the contribution rates are high during the second survey period. This may be because the wind blows from the river frequently as shown in Fig. 2-4.

(2) Soil+Road dust

The reason why the contribution rates of the Soil+Road dust are high at MS1, MS4 and MS5 is shown as follows: MS1 locates at 90 m west from Sukhumvit Road (traffic volume is 77,000 cars/day) and MS4 locates at 100 m east from Sukhumvit Road (traffic volume is 35,000 cars/day), so these stations may be suffering from road dust. MS5—where the contribution rates of Soil+Road dust are highest—locates at 120 m south from Theparak Road (unpaved road). Furthermore, all around this station the surface soil is exposed. So this station may be suffering from road dust and blown-up soil.

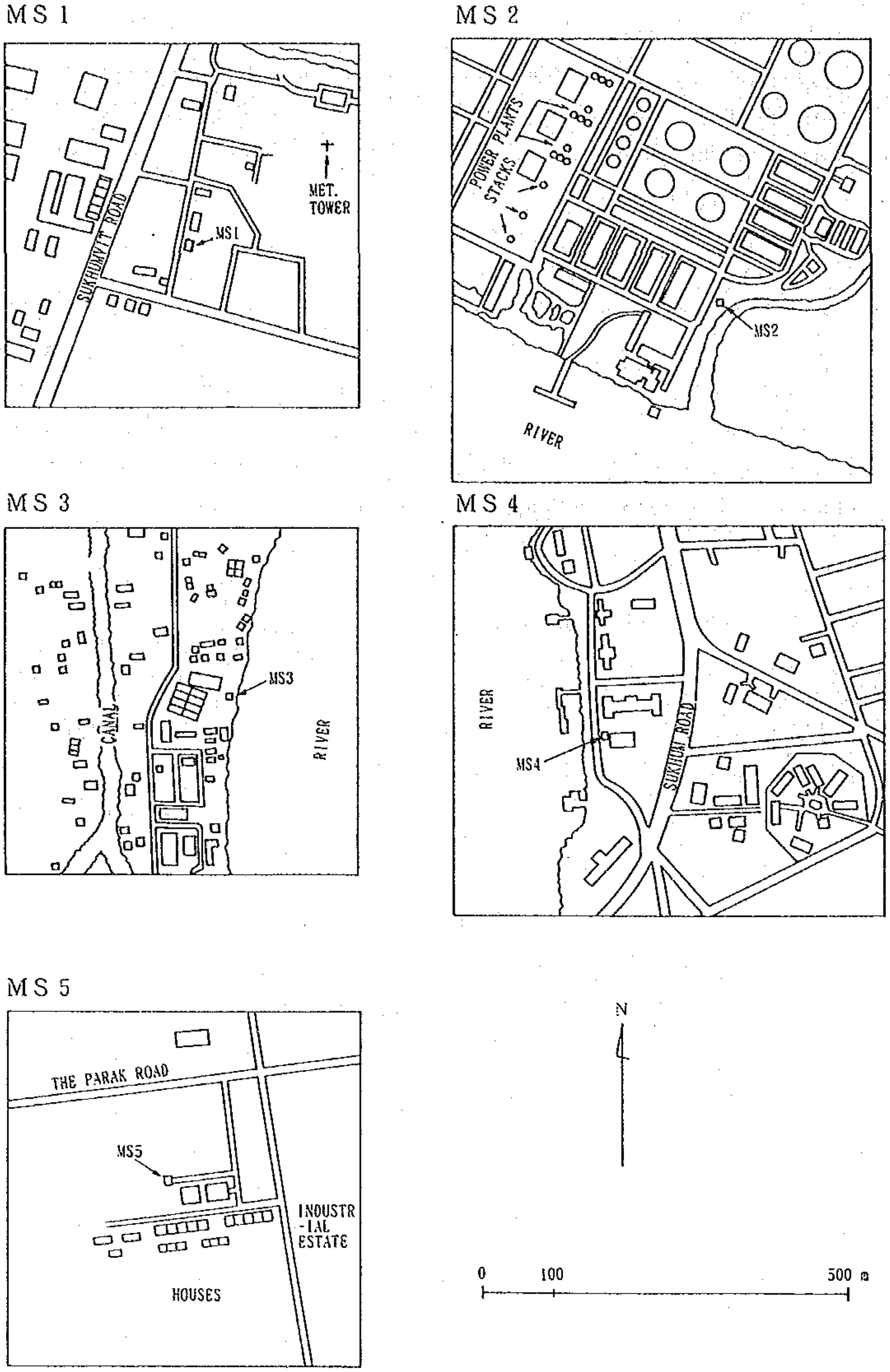

Fig. 2-3 Location of the Monitoring Sites

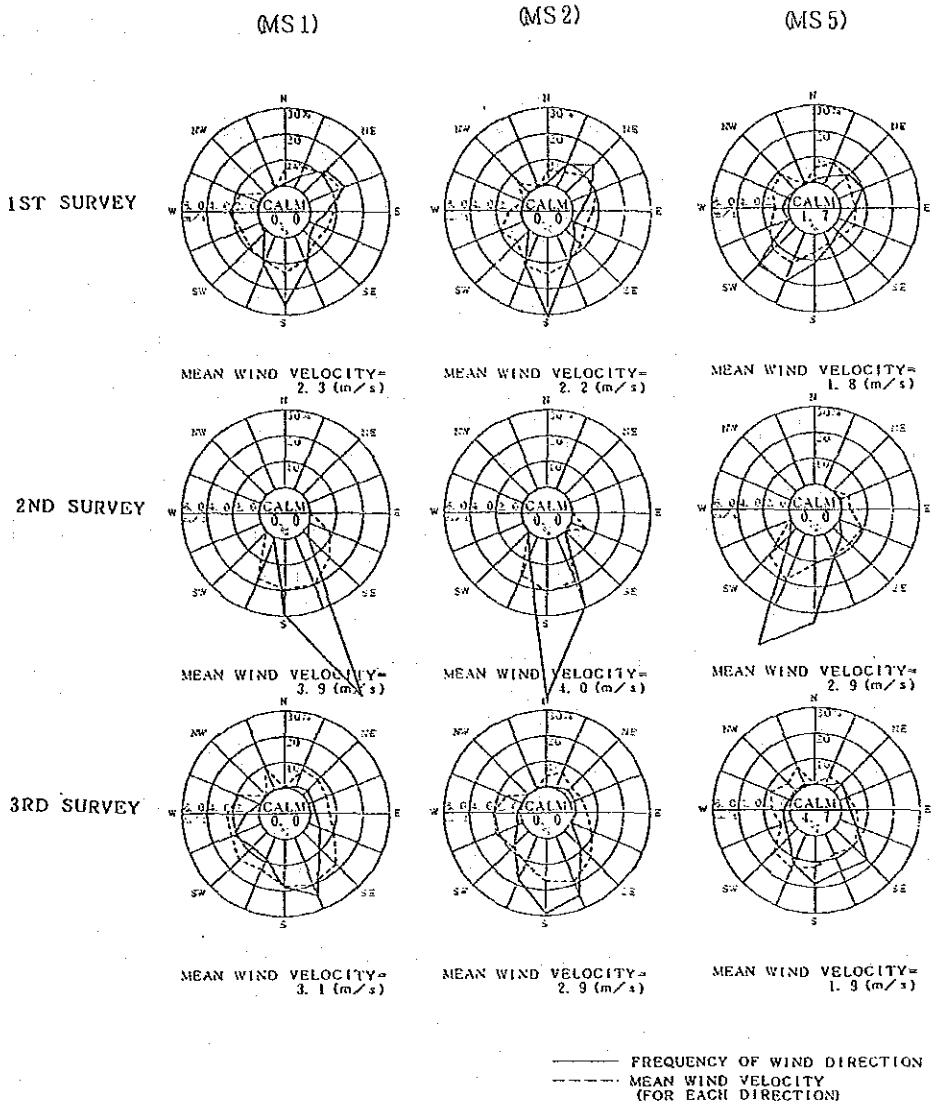

Fig. 2-4 Wind that Arose during the Short-term Field Survey

(3) Diesel automobile, Gasoline automobile

The reason why the contribution rates of Diesel automobile and Gasoline automobile are high at MS1 and MS4 may be the same as above. The contribution of Diesel car varies 23~48 pct whereas that gasoline car maintains only 0~5 pct.

(4) Iron and Steel industry

The reason why the contribution rates of the Iron and Steel industry are high at MS3 may be that the iron mill (electrosteel) stands on the other side of Chao Phraya River. The wind mostly blew from steel plant site (NE) in the 1st survey period, which is thought the cause of higher contribution. The frequency of NE winds was less in the 2nd and 3rd survey periods.

(5) Fuel oil combustion

Though the contribution rates of Fuel oil combustion are relatively high at MS2 and MS3, the absolute rates are low (about 2%). Furthermore, at the other stations the contribution rates are under 1%. Especially, the rates at MS5 are very low (about 0.1%). Besides, the contribution rates of Fuel oil combustion at MS2—which stands in the power plant ground—are low (about 1%) may be because of high chimney (104 m height).

(6) Glass industry

The contribution rates of Glass industry varies from 0.1% to 2% and have no regional character. However, to be considered is that aluminum smelting factory also emits same chemical components as those of glass factories, and both share the contribution.

(7) The contribution rates of natural products and the artificial producdts

Though it was not possible to distinguish between Soil (natural product) and Road dust (artificial product) in this estimate, the results show that the largest emission source type of artificial products is the Diesel automobile (black smoke in the exhaust gas) and the second emission source is Road dust and the contribution rates of Fuel oil combustion and the Iron and Steel industry are very low (several percent). However, as the ratio of natural products and artificial products varies seasonally, it can be regarded as fifty-fifty. This estimated result agrees with the common value measured in many countries.

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PART VI REMEDIAL EFFORTS AGAINST EMISSION SOURCE IMPROVEMENTS AND THEIR EFFECTIVENESS

1. Summary

In view of what is discussed in the previous Chapter, it is clear that the ambient concentrations of SO_2 and NO_2 in Samut Prakarn province today (as of 1988) meet the environmental standards of Thailand at all areas. However, if the 6th state economic and social development plan is completed and the succeeding similar plan are carried forward, it is most likely that environmental deterioration is inevitable as the result of such developments. Accordingly, we have first predicted the ambient concentrations of SO_2 and NO_2 for the future years of 1992 and 1999 assuming that the economic development is carried out without appropriate control measures taken for the emission sources. This revealed that NO_2 ambient concentration would exceed the environmental standard in 1999 in this area. Then, concrete remedial measures for emission sources and their effectiveness have been studied to improve NO_2 ambient concentrations in future years. In addition, while SO_2 ambient concentration will not exceed the environmental standard even if economic and social development is made progress, the contribution rates at high concentration points are greatly occupied by factories; in Thailand no SO_2 emission control for factories has presently been enforced, very likely causing a problem of unfairness among factories relating to SO_2 emission under the status quo. This part, therefore, discribes the methods of SO_2 emission control for factories and the *forecast of ambient concentration of SO_2 after implementation of emission control in future (1999).*

2. Emission Volumes of SO_2 and NO_x in Future Years without Countermeasures against Sources

2.1 Factory

Though it goes as a rule that the air pollutant emission volumes in future years have to be estimated based on the detailed emission source data reported by enterprises. In this study, however, the estimation was made by resorting to another method because such data were unavailable from enterprises. Namely, what are used as information for forecasting are the increase rate of the gross domestic product price (from the Thailand Development Research Institute; G.D.P. by Sector, July 1988) and the elastic modulus of energy. The fuel consumptions in future years were firstly predicted by using equation (2-1). The emission volumes of SO_2 and NO_x in future years were then calculated from these values multiplied by the emission factors of SO_2 and NO_x:

$$W_t = W_o \times (1+e \cdot p)^n \quad \text{.......} \quad (2\text{-}1)$$

where

W_t : fuel consumptions of factories in 1992 and 1999

W_o : fuel consumptions of factories in 1988

p : increase rate of the gross product price

e : modulus of elasticity; 0.8

n : number of years

The values of p (annual rate) are 0.0578 for 1988~1991, 0.0513 for 1991~1996 and 0.0542 for 1996~2001. The increase rate of the fuel consumptions in 1992 and 1999 obtained by substituting these values for the equation (2-1) compared to 1988 base year are 1.192 and 1.590, respectively. Quantities of SO_2 and NO_x emitted from factories in future years obtained from such calculations are shown in Table 2-1 and Fig. 2-1. In estimation of the SO_2 and NO_x emission volumes in future years, the factories who will be established in the industrial estate constructed by Thai government in the Samut Prakarn industrial district, which are shown in Table 2-2, were also added as the future emission sources. The fuel consumptions of these factories were estimated by knowing the fuel consumption units per one employee (Chapter IV, Table 2-27).

Table 2-1 SO_2 and NO_x Emission Volume Emitted from Samut Prakarn Prefecture in Future Years

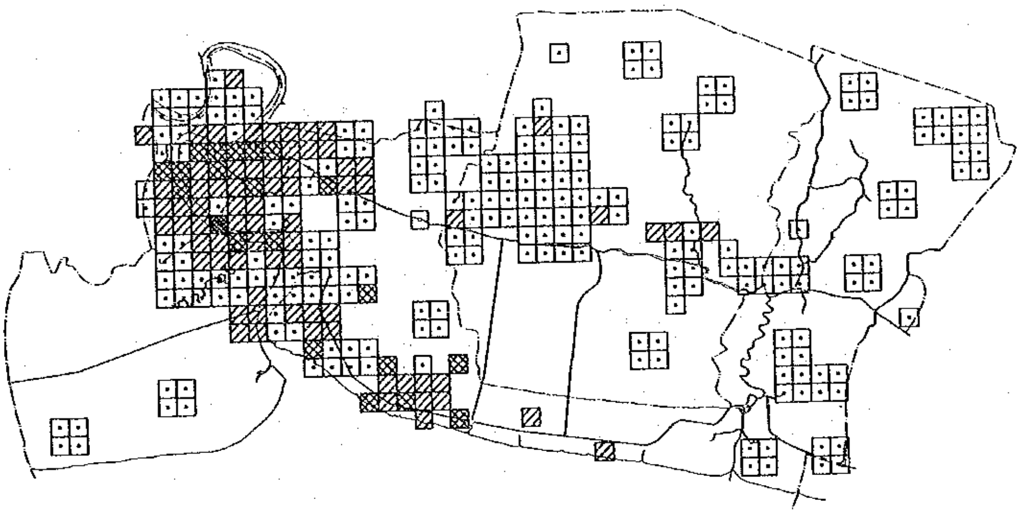
Name of source		Type of source	SO_2 emission volume (ton/year)			NO_x emission volume (ton/year)		
			1988	1992 (92/88)	1999 (99/88)	1988	1992 (92/88)	1999 (99/88)
Stationary sources	Questionnaire return	point	13649	16269 (1.19)	21701 (1.59)	8108	9665 (1.19)	12892 (1.59)
	Questionnaire nothing	area	4681	5580 (1.19)	7443 (1.59)	712	848 (1.19)	1132 (1.59)
	Industrial estate	area	—	298 (—)	298 (—)	—	28 (—)	28 (—)
	Sub total		18330	22147 (1.21)	29442 (1.61)	8820	10541 (1.20)	14052 (1.59)
Road way		line	1474	1829 (1.24)	2261 (1.53)	7812	10448 (1.34)	15119 (1.94)
Vessels and Ferryboats	Vessels (sailing)	point	1263	1505 (1.19)	2007 (1.59)	1623	1935 (1.19)	2581 (1.59)
	Ferryboats (anchoring)	point	8	11 (1.38)	17 (2.16)	26	36 (1.38)	57 (2.16)
	Ferryboats (sailing)	point	59	82 (1.38)	128 (2.16)	221	304 (1.38)	476 (2.16)
	Sub total		1330	1598 (1.20)	2152 (1.62)	1870	2275 (1.22)	3114 (1.67)
TOTAL			21134	25574 (1.21)	33855 (1.60)	18502	23264 (1.26)	32285 (1.74)

Table 2-2 Summary of Factories Planned for Construction

Site	Factory name	Product	Code	Area (m^2)	Number of employee (person)	Fuel gener. (0.01 kl/y /per.)	Fuel consumption (kl/y)	SO_2 emission volume (t/y)	NO_x emission volume (t/y)
Bangplee Industrial Estate	Eternal Petrochemical CO.,LTD	Phthalic anhydride	42	64,488	160	250	400	18.60	1.74
	Kitz (Thailand) CO.,LTD	Brass & Bronze valve	64(8)	1,600	150	72	108	5.02	0.47
Bangpoo Industrial Estate	Carbee Thanawat CO.,LTD	Prawn Chip	10(2) 10(2)	5,054 6,384	(163) 206	438	1,616	75.14	7.03
	Southeast Asian Packaging CO.,LTD	Canned food	7(1) 7(1)	13,340 6,616	90 700	438	3,460	160.89	15.05
	Lion Tire (Thailand) CO.,LTD	Tire & Tube	51	26,194	205	250	513	23.85	2.23
	Shinfu Dyeing CO.,LTD	Dyeing	22(2)	11,830	200	155	310	14.42	1.35
TOTAL							6,407	297.92	27.87

SO_2 in 1992

Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	234
	1.0 ~ 10.0	73
	10.0 ~ 100.0	20
	100.0 ~	1



SO_2 in 1999

Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	217
	1.0 ~ 10.0	88
	10.0 ~ 100.0	22
	100.0 ~	1

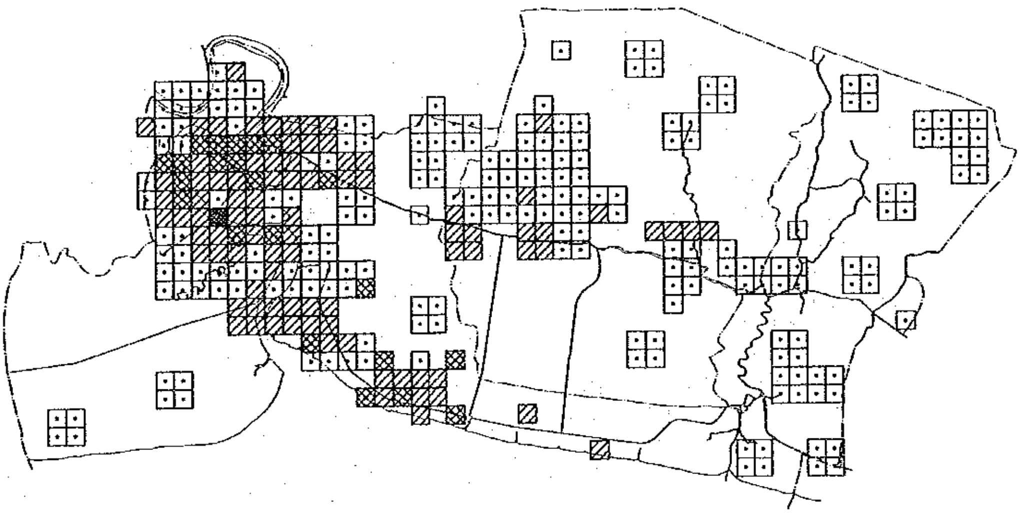
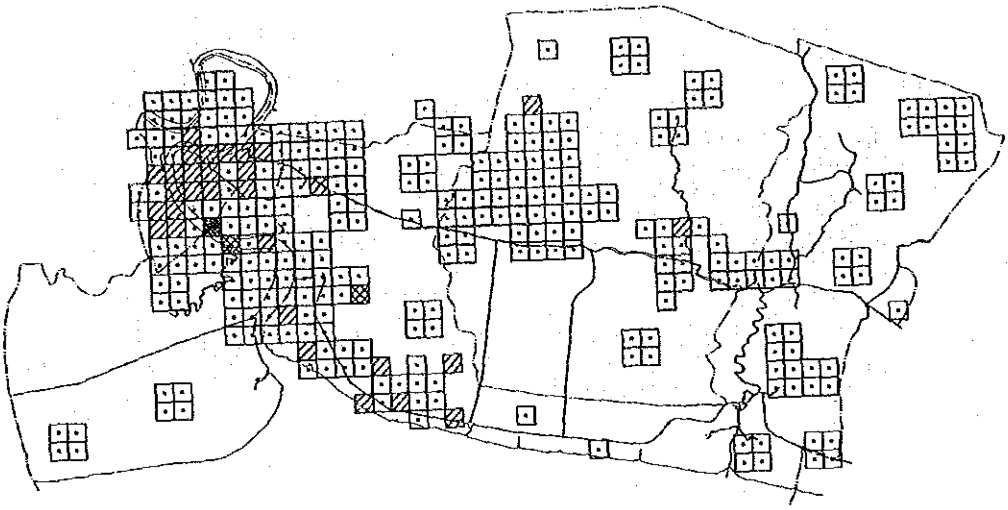


Fig. 2-1(1) SO_2 Emission Volume by Mesh Emitted from Factories

NO$_x$ in 1992

Rank	Emission volume NOx (Nm³/H)	Number of mesh
	0.0 ~ 1.0	288
	1.0 ~ 10.0	30
	10.0 ~ 100.0	2
	100.0 ~	1



NO$_x$ in 1999

Rank	Emission volume NOx (Nm³/H)	Number of mesh
	0.0 ~ 1.0	282
	1.0 ~ 10.0	35
	10.0 ~ 100.0	3
	100.0 ~	1

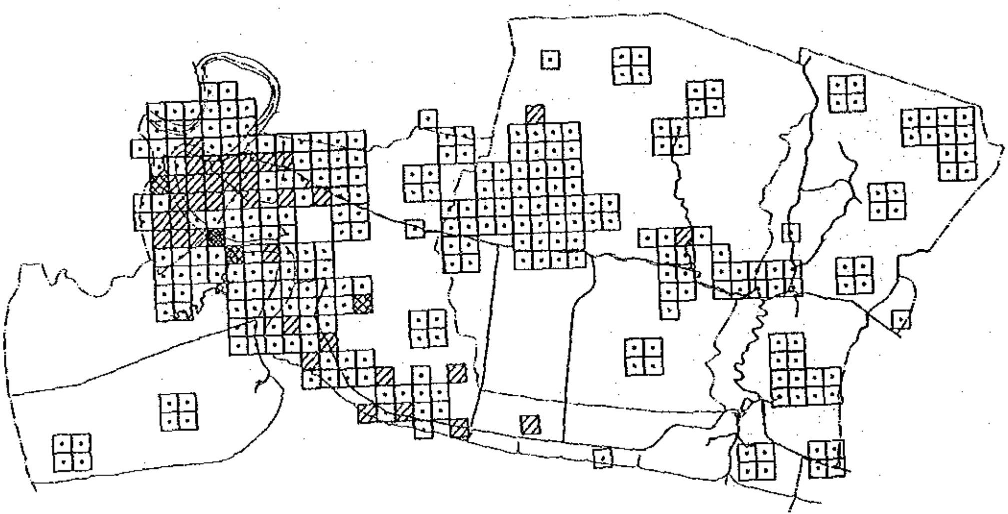


Fig. 2-1(2) NO$_x$ Emission Volume by Mesh Emitted from Factories

2.2 Vessels

The growth of the number of vessels was considered proportional to the growth of the gross product price and thus the number of vessels were estimated in the same manner as the factory. Then this number was multiplied by the SO_2 and NO_x emission factor for calculation of the SO_2 and NO_x emission volume of the coming years. The result is shown in Table 2-1 and Fig. 2-2.

2.3 Vehicles and Ferryboats

Based on the number of cars for year 1991 and 2001 listed in the forecast of the number of cars owned in Samut Prakarn province (Mr. Mikimasa Yoshida; Asia Economy Institute, Ms. Chuta Manasphaibul; Associate Professor, Faculty of Economics, Chulalongkorn University, Ms. Orajit Singkalavanich; Director, Planning Division, Dept. of Export Promotion, Ministry of Commerce, 1980 Economic Development Policy in Thailand, Asia Economy Institute, 1989), the number of cars for 1992 and 1999 was estimated and this number was multiplied by the SO_2 and NO_x emission factors to calculate the SO_2 and NO_x emission volume from cars in the future. The result is shown in Table 2-1 and in Fig. 2-3. The growth of the number of cars owned is as shown in Table 2-3.

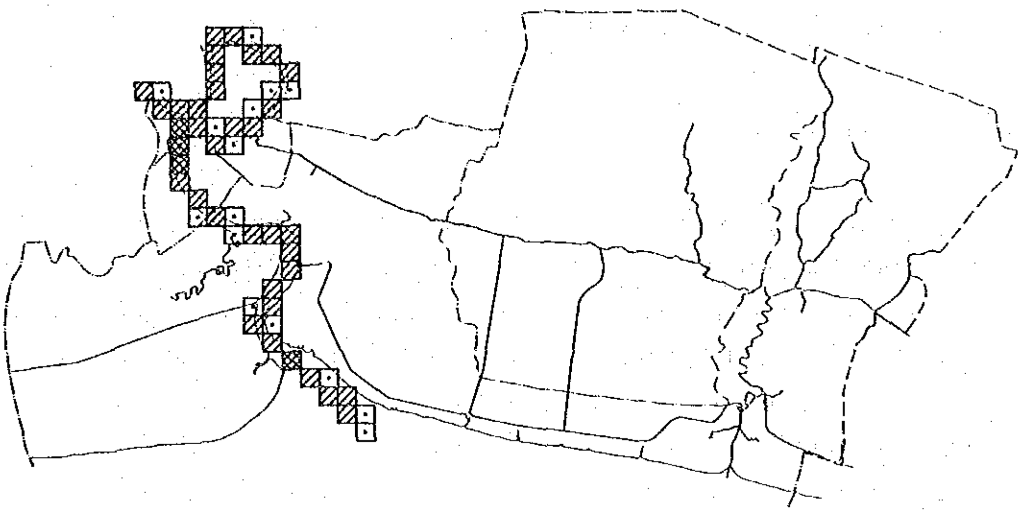
Table 2-3 Growth of Number of Cars Owned

Vehicle type	Growth of number of cars owned		Remarks
	1992/1988	1999/1988	
Light vehicle Heavy vehicle	1.241	1.532	Growth rate of number of trucks and buses was applied.
Gasoline LPG	1.529	2.725	Growth rate of number of cars was applied.
Motor cycle	1.526	3.034	Growth rate of number of motor bicycles was applied.

Future emission volumes of SO_2 and NO_x from ferry boats were calculated as follows: We assumed that the number of ferryboats in operation was proportional to the number of cars running on Puchao Saming Phla Road and that it increased at rates of 1992/1988=1.376 and 1999/1992=2.155. On the basis of this assumption, the number of ferryboats to be operated in future was calculated and then, to calculate the SO_2 and NO_x emission volume, that numbers were multiplied by the emission factors of SO_2 and NO_x. The results are shown in Table 2-1 and Fig. 2-2.

SO_2 in 1992

Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	15
	1.0 ~ 2.0	33
	2.0 ~ 3.0	4



NO_2 in 1999

Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	14
	1.0 ~ 2.0	18
	2.0 ~ 3.0	18
	3.0 ~	2

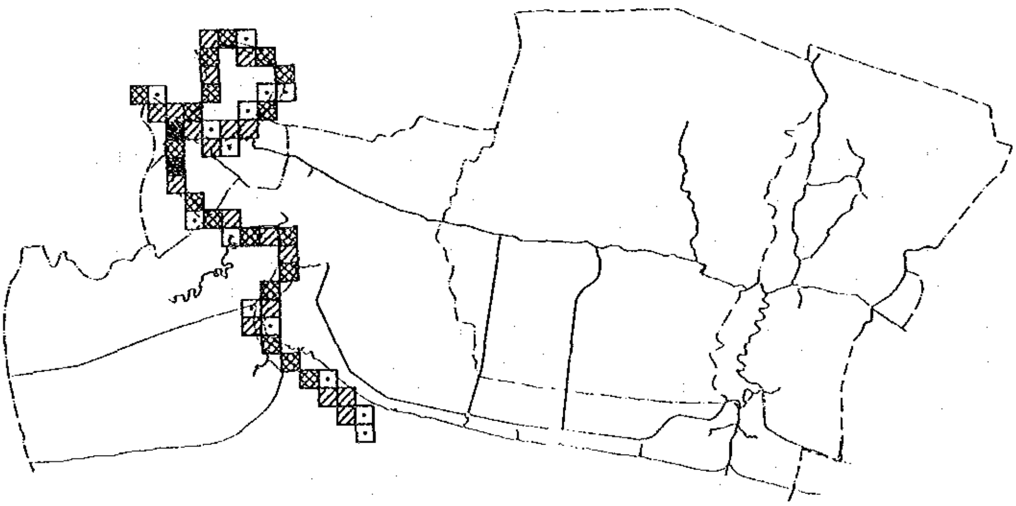
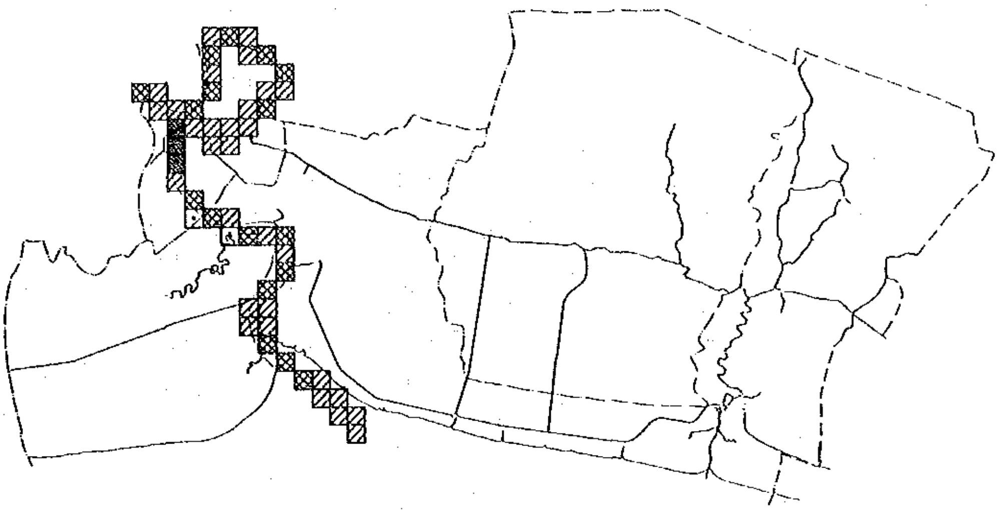


Fig. 2-2(1) SO_2 Emission Volume Emitted from Vessels and Ferryboats

NO_x in 1992

Rank	Emission volume NOx (Nm³/H)	Number of mesh
⊡	0.0 ~ 1.0	2
▢	1.0 ~ 3.0	30
▩	3.0 ~ 5.0	17
▣	5.0 ~	3



NO_x in 1999

Rank	Emission volume NOx (Nm³/H)	Number of mesh
⊡	0.0 ~ 1.0	2
▢	1.0 ~ 3.0	29
▩	3.0 ~ 5.0	17
▣	5.0 ~	4

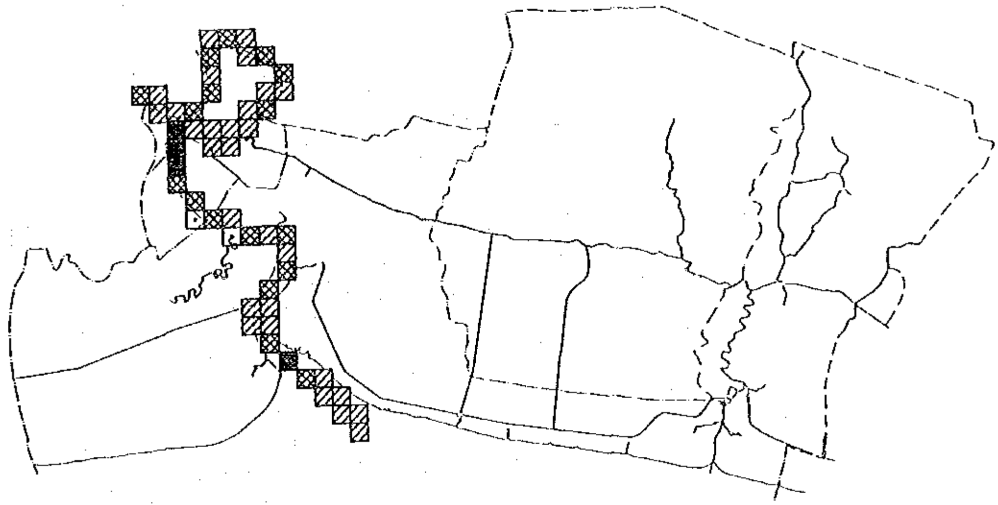
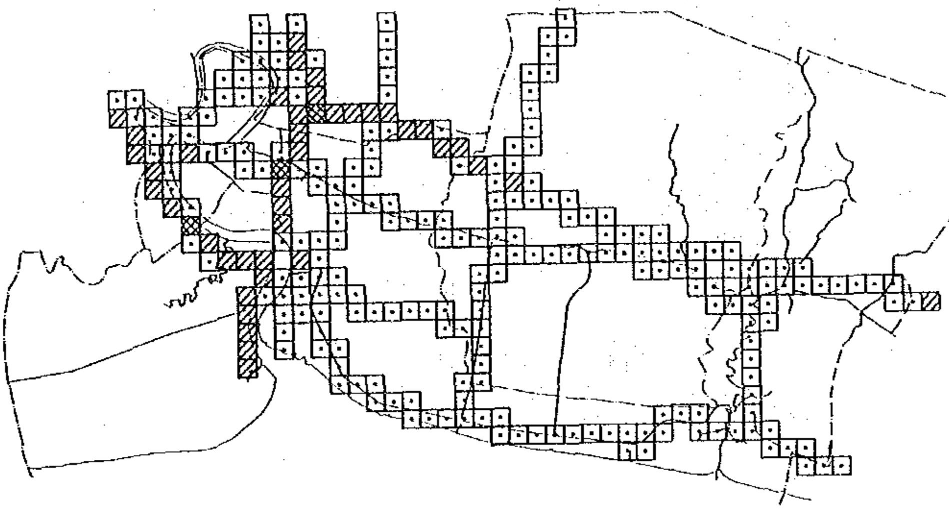


Fig. 2-2(2) NO_x Emission Volume Emitted from Vessels and Ferryboats

SO_2 in 1992

Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
	0.0 ~ 0.5	226
	0.5 ~ 1.0	40
	1.0 ~ 2.0	3



SO_2 in 1999

Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
	0.0 ~ 0.5	202
	0.5 ~ 1.0	52
	1.0 ~ 2.0	15

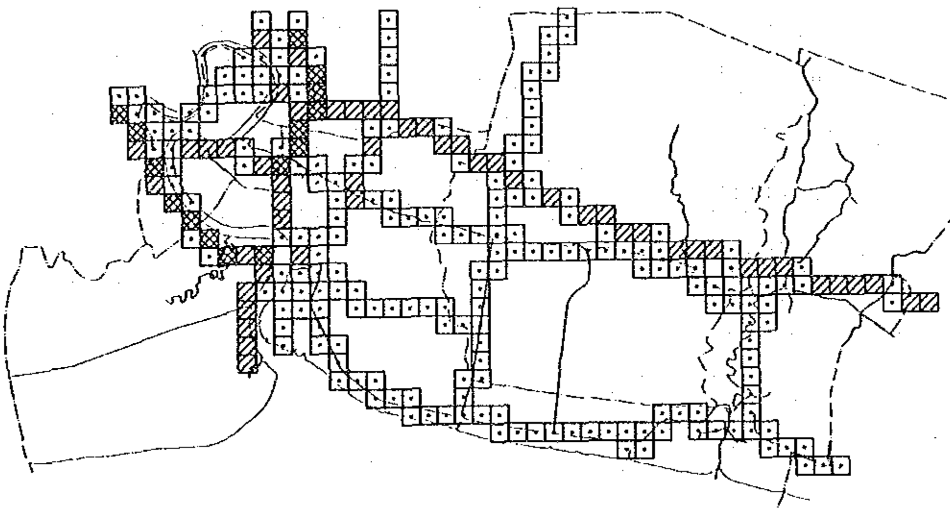
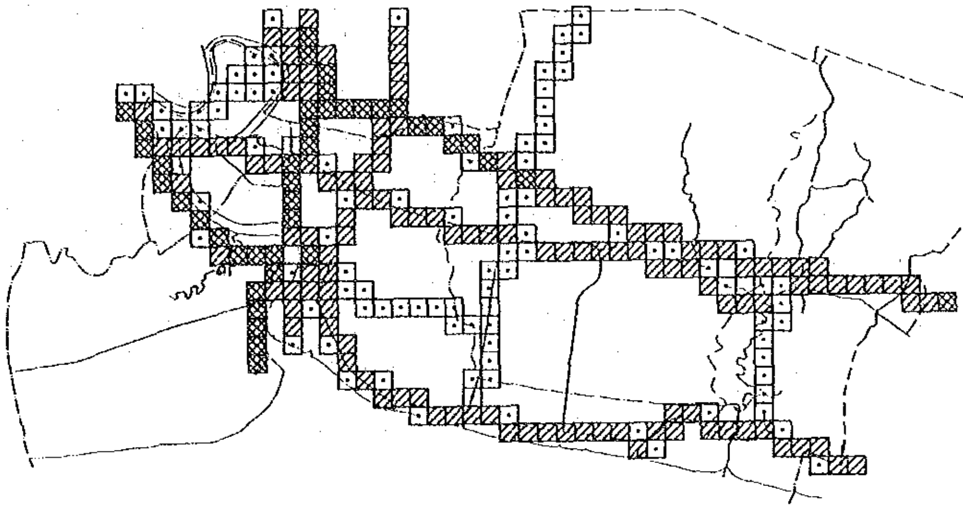


Fig. 2-3(1) SO_2 Emission Volume Emitted from Vehicles

NO_x in 1992

Rank	Emission volume NO_x (Nm³/H)	Number of mesh
	0.0 ~ 1.0	93
	1.0 ~ 4.0	129
	4.0 ~ 10.0	41



NO_x in 1999

Rank	Emission volume NO_x (Nm³/H)	Number of mesh
	0.0 ~ 1.0	86
	1.0 ~ 4.0	104
	4.0 ~ 10.0	69
	10.0 ~	11

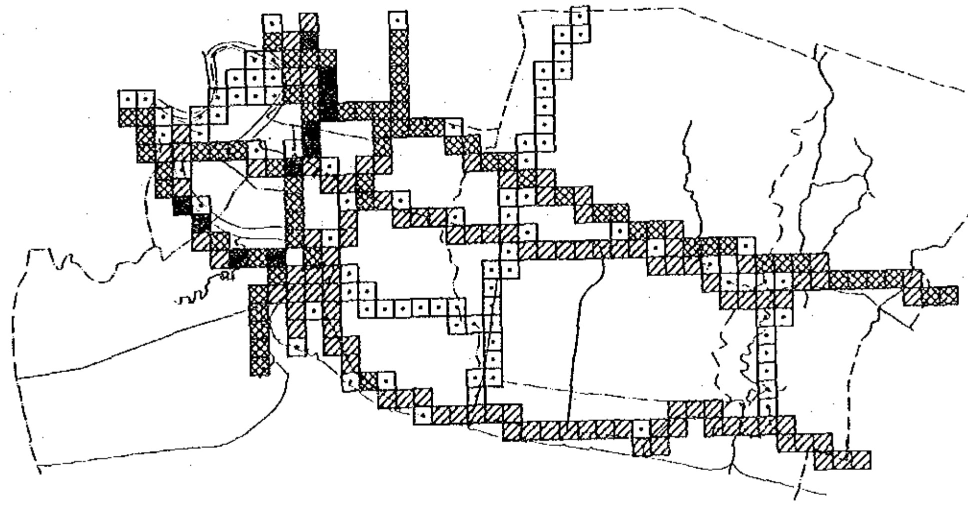
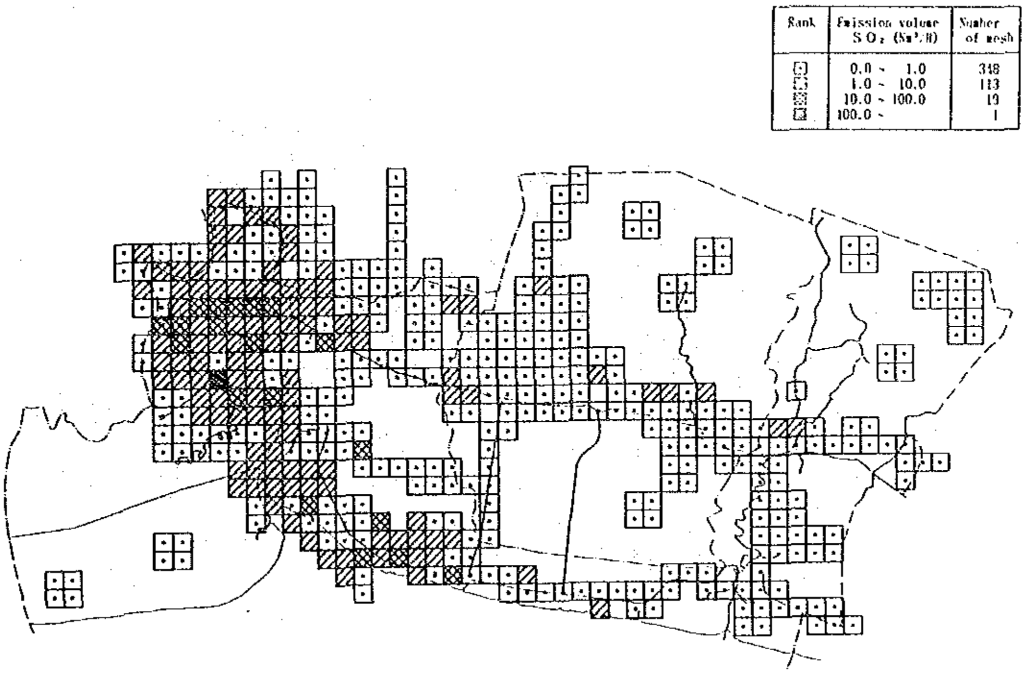


Fig. 2-3(2) NO_x Emission Volume Emitted from Vehicles

2.4 SO_2 and NO_x Emission Volumes Emitted from the Whole Samut Prakarn Region in Future Years in the Case of Taking No Countermeasures for Emission Sources

The SO_2 and NO_x emission volume from factories, cars, vessels, and ferries in Samut Prakarn Province for the case where there are no countermeasures for emission sources were summed up. This result is shown in Table 2-1. The SO_2 and NO_x emission volumes from the whole Samut Prakarn Province by mesh are shown in Fig. 2-4. These results show that the total emission volumes of SO_2 and NO_x in 1992 are 25,574 and 23,264 metric ton/year respectively. Those figures of 1992 compared with emission volumes in 1988 (SO_2; 21,134 t/y, NO_x; 18,502 t/y) show the increase of both pollutants, 1.21 times in SO_2 and 1.26 times in NO_x against the base yeaer of 1988. In similar manner, the SO_2 and NO_x emission volumes in 1999 were estimated to be 33,855 and 32,285 tons per year respectively, or 1.60 and 1.74 times increase against the base year of 1988.

SO_2 in 1992



SO_2 in 1999

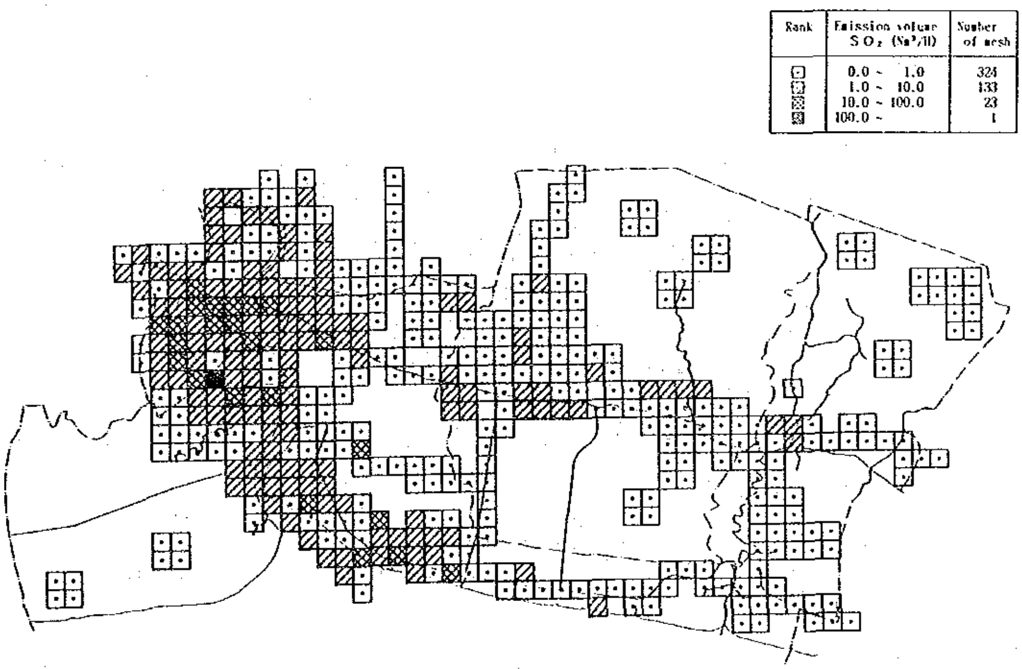
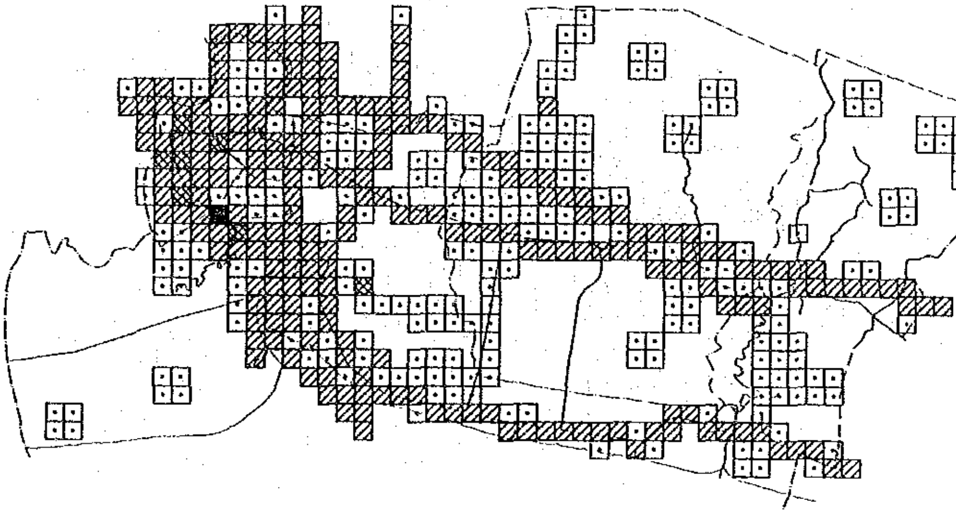


Fig. 2-4(1) SO_2 Emission Volume Emitted From All Emission Sources

NO_x in 1992

Rank	Emission volume NOx (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	245
	1.0 ~ 10.0	222
	10.0 ~ 100.0	7
	100.0 ~	1



NO_x in 1999

Rank	Emission volume NOx (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	227
	1.0 ~ 10.0	226
	10.0 ~ 100.0	21
	100.0 ~	1

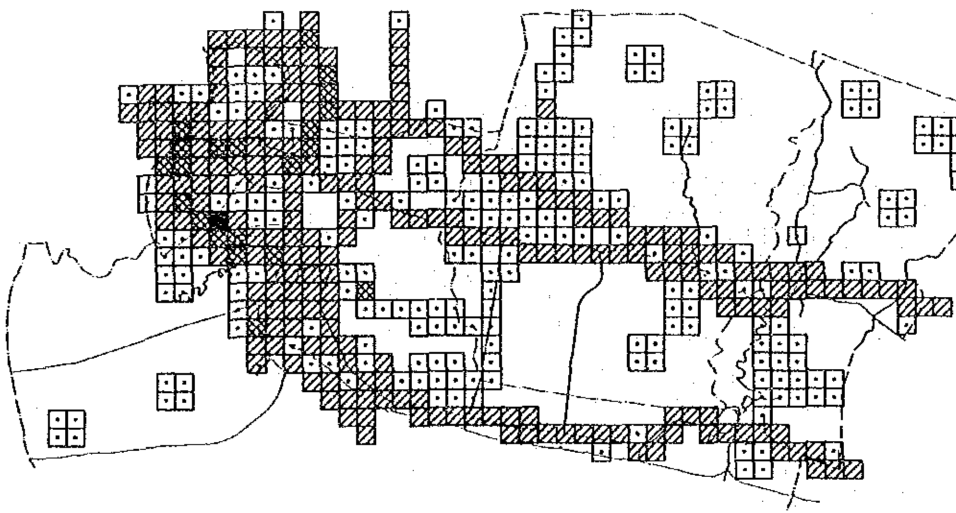


Fig. 2-4(2) NO_x Emission Volume Emitted From All Emission Sources

3. Forecasting of Ambient SO_2 and NO_2 Concentrations in the Case of Taking No Countermeasures Taken against Emission Sources

3.1 Modeling of Smoke Sources Data

In order to predict SO_2 and NO_2 ambient concentration in the future years by using SO_2 and NO_x emission volume mentioned in the previous chapter as input data, the data of factory smoke sources (stationary point sources) were modeled. Namely, we supposed that the measures for increasing the fuel consumption of existing facilities in factories are taken according to the following priority order. A list of measures for increasing the fuel consumption is shown in Table 3-1:

① Increase of load factor
② Extension of operating hours
③ Fuel distribution to the same facilities
④ Increase of facilities with the same scale as the existing ones

Table 3-1 Measures for Increasing the Fuel Consumption

Measures	Year of 1992	Year of 1999
① Increase of load factor	First, increase the load factor without changing the operating hours. Increase of the load factor normally leads to the increase of the flue gas volume.	
② Extension of operating hours	If the step ① can't absorb the increment of the fuel consumption, extend the operating hours.	
③ Fuel distribution to the same facilities	If the steps ① and ② can't absorb it, distribute the fuel to a facility with a surplus burning capacity, if there is one.	
	(Put one unit of facilities out of service into operation.) 3-47-3	1-64-3: Put facilities out of service into operation.) 3- 5-2: Put facilities out of service into operation.) 3- 9-3: Has a surplus capacity.) 3-14-4: Put facilities out of service into operation.) 3-47-3: Put facilities out of service into operation.) 3-57-2: Put facilities out of service into operation.)
④ New cincrease of facilities	If steps ①, ② and ③ can't apply it, newly increase the facilities.	
	2-12-101 3- 4-101 2 facilities above were newly increased.	1-51-101 2- 3-101 2-12-101 2-17-101 3- 4-101 3-14-101 3-23-101, 102, 103 3-33-101 3-42-101 3-57-103 3-77-101 3-78-101 3-105-101 15 facilities above were newly increased.

3.2 Diffusion Condition

The simulation model which was used to predict the future ambient pollutant concentrations is an atmospheric diffusion model which was mentioned in Chapter V since that model can well reproduce the actually measured present ambient pollutant concentrations. For the meteorological condition necessary for forecasting the future ambient pollutant concentrations, the same condition as applied to calculation of the present concentration was employed on the assumption that the average annual meteorological condition will not significantly change in future, as well.

3.3 Comparison of Ambient Pollutant Concentrations of the Whole Area to the Environmental Control Standards of Thailand

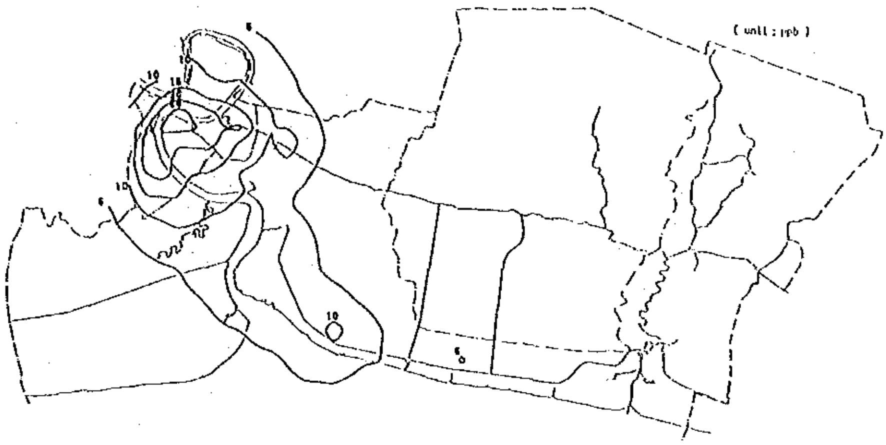
We predicted the annual average ambient concentrations of SO_2, NO_x and NO_2 in all areas of Samut Prakarn prefecture in 1992 and 1999. The results are shown in Fig. 3-1 and Table 3-2. The number of mesh by concentration rank is also shown in Table 3-3. These results revealed that if no countermeasures for emission sources are taken, as indicated in Table 3-4, both SO_2 and NO_2 fulfilled the environmental standatds of Thailand in all areas in terms of current figures (1988), whereas NO_2 would exceed the standards at 31 points in 1999. Fig. 3-2 shows the points where NO_2 would exceed the environmental standard.

3.4 Contribution Rate by Emission Sources

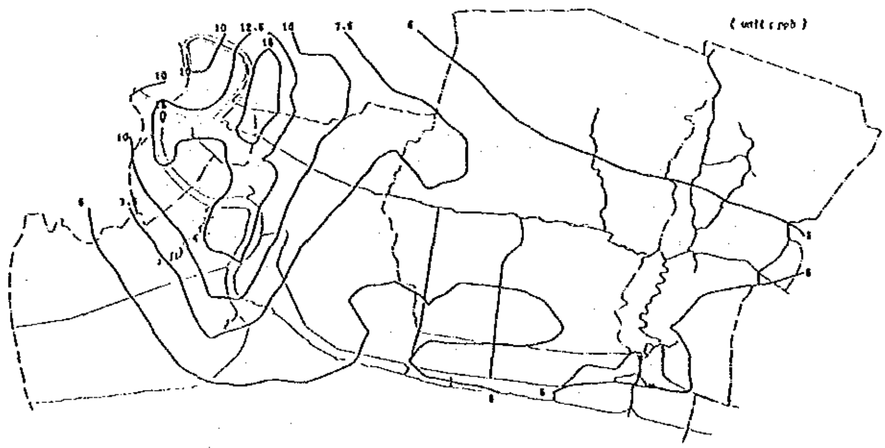
The points where NO_2 ambient concentration will exceed the environmental standards in future are as shown in Fig. 3-2. The contribution rates by emission sources of high contribution-top 8 points were calculated, and the results are shown in Table 3-5. While the ambient concentration of SO_2 will not exceed the environmental standard, the table also shows the contribution rates by emission sources at high concentration-top 8 points for SO_2 ambient concentration.

According to these results, the contribution rates by emission sources at the points where NO_2 concentration will exceed the environmental standard in 1999 are 2.6 to 7.6% for factories, 32.4 to 83.4% for cars, 2.2 to 11.4% for ships, and 0.1 to 35.6% for ferryboats, demonstrating a great contribution rates by cars. This trend is same for the rates in 1992. As for SO_2, contribution by factories occupies about 75 to 88% in both 1992 and 1999 against 6% for cars.

SO_2



NO_2



NO_x

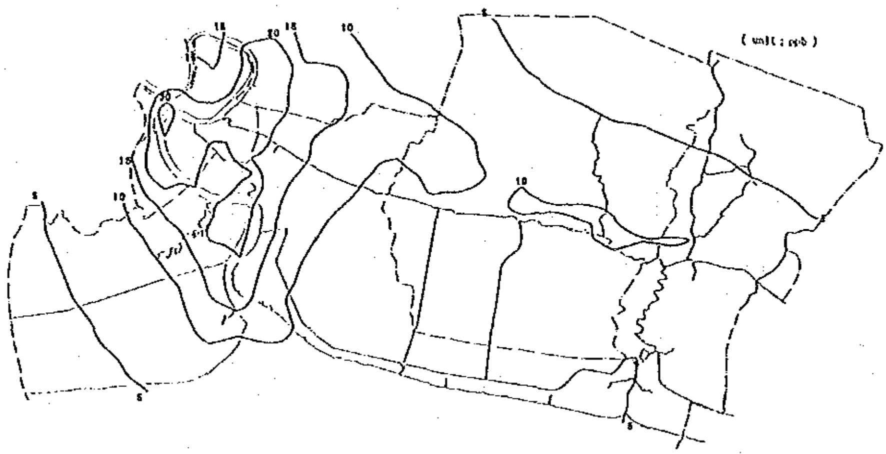
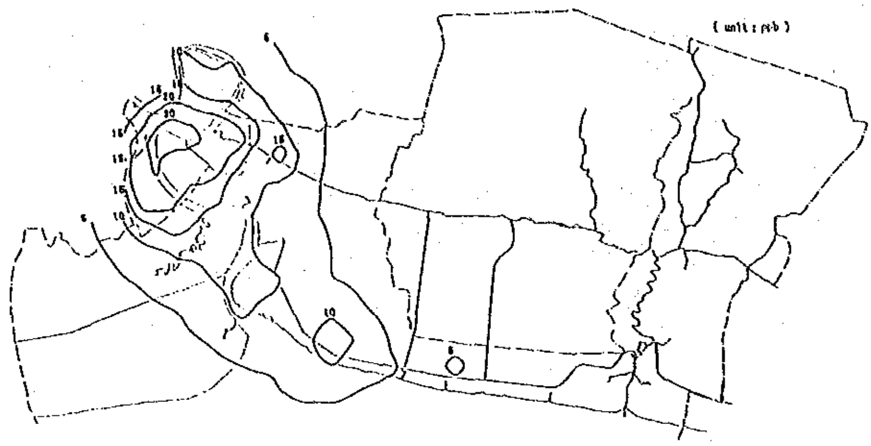
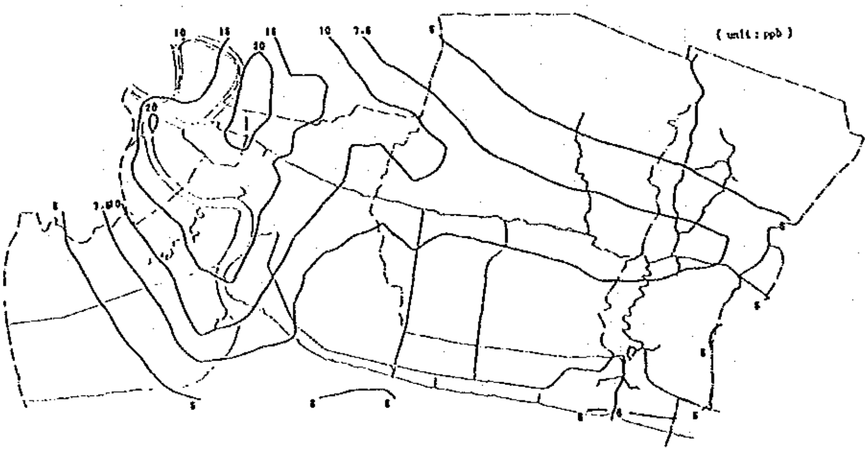


Fig. 3-1(1) Atmospheric Pollutant Concentrations in Samut Prakarn Province in the Case of Taking No Countermeasures for Emission Sources (in *1992*)

SO_2



NO_2



NO_x

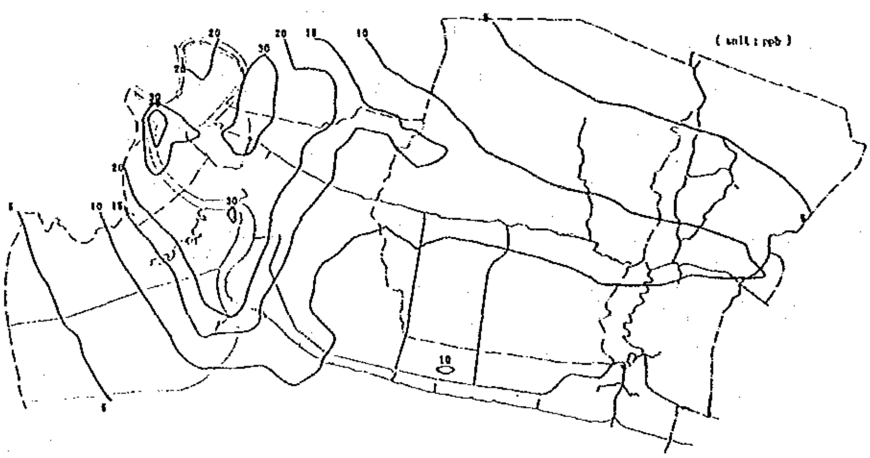
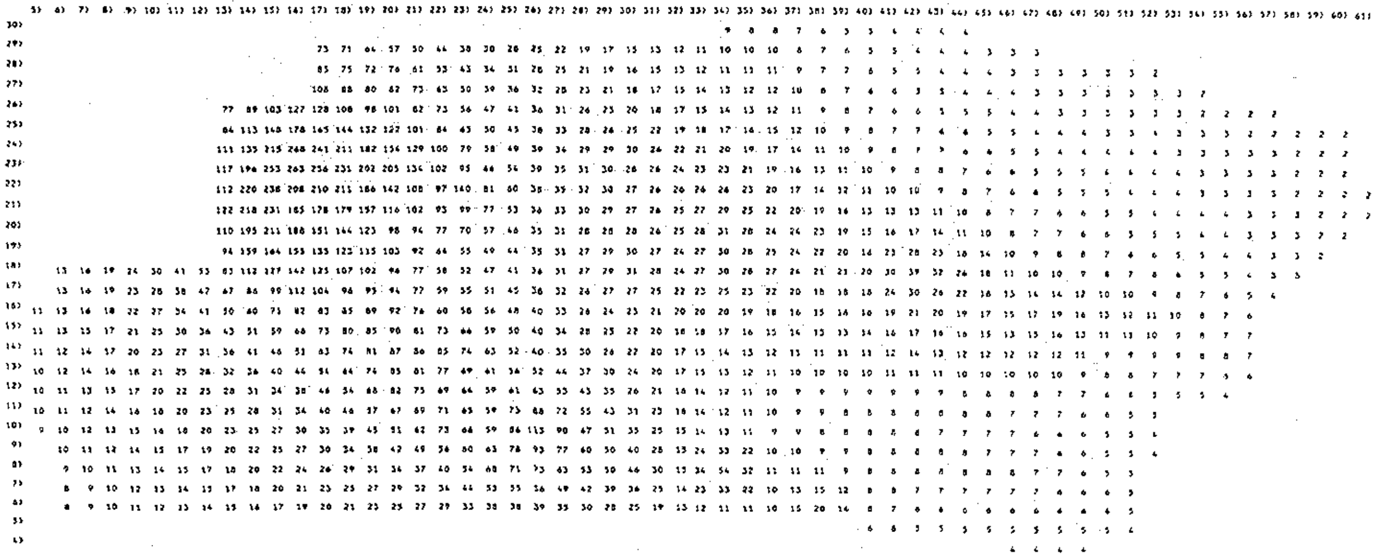


Fig. 3-1(2) Atmospheric Pollutant Concentrations in Samut Prakarn Province in the Case of Taking No Countermeasures for Emission Sources (in 1999)

Table 3-2(1) Average Annual SO_2 Concentrations in Samut Prakarn Province in the Case of Taking No Countermeasures for Emission Sources (Unit: 0.1 PPb)

in 1992



in 1999

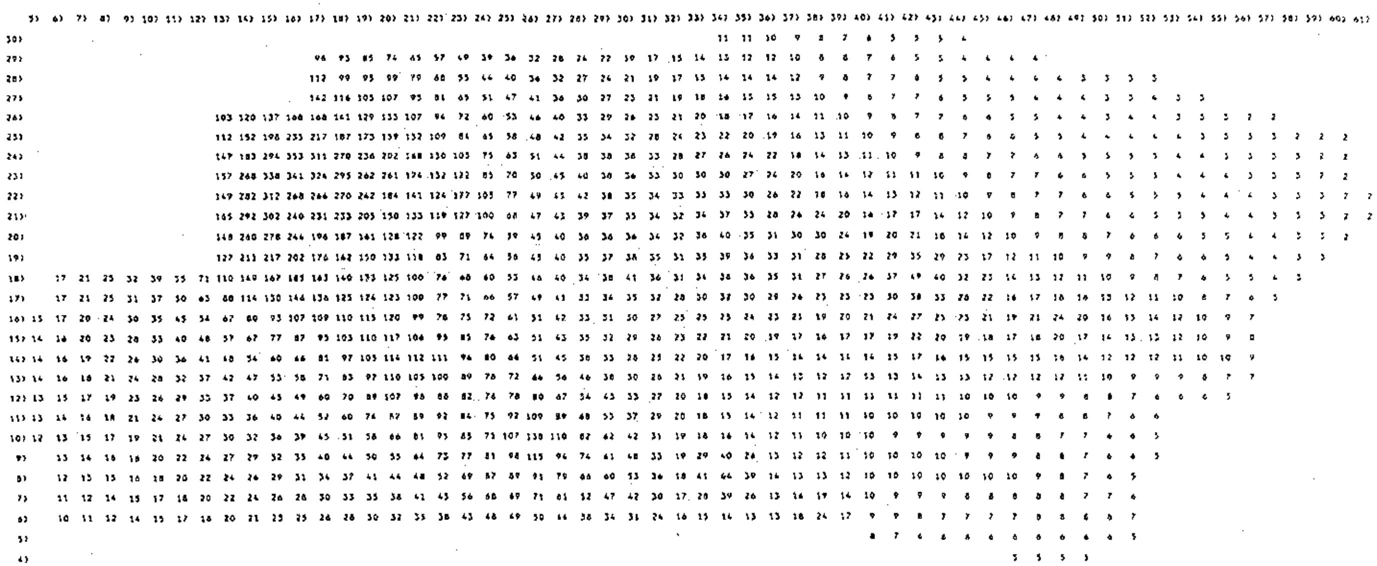


Table 3-2(2) Average Annual NO_2 Concentrations in Samut Prakarn Province in the Case of Taking No Countermeasures for Emission Sources (Unit: 0.1 PPb)

in 1992

	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
30																														40	39	38	36	33	31	29	29	29	29	29																	
29													79	85	98	114	128	125	112	89	86	83	74	65	60	56	52	49	46	43	41	40	37	35	33	32	31	30	30	29	29	29	29														
28													67	91	106	129	141	150	134	97	96	95	85	73	65	59	55	53	49	45	43	42	39	37	35	34	33	32	30	29	29	29	29	28	28	28	28	28									
27													97	99	110	133	148	172	140	108	108	106	93	79	71	63	60	57	53	50	47	44	42	39	38	36	35	34	33	31	31	31	30	30	29	28	28	28	28	28							
26									94	96	99	105	106	107	117	138	153	180	134	122	120	110	102	86	77	66	65	62	58	54	51	47	44	41	40	38	37	36	35	34	33	33	32	31	30	28	28	28	28	28	28	28	28				
25									101	109	120	118	113	116	127	139	160	174	130	116	118	114	100	85	81	77	76	71	65	59	55	50	47	44	42	43	40	39	37	36	36	35	34	34	33	32	31	31	31	31	30	30	30	29	29	28	
24									104	105	134	130	127	131	134	142	171	148	131	121	117	113	99	84	85	86	82	79	72	66	59	53	50	47	45	43	42	41	40	38	38	38	37	36	35	35	34	34	33	33	32	32	31	30	29	28	
23									101	111	147	132	134	135	137	156	149	134	125	114	110	102	91	81	81	82	82	83	77	72	65	58	54	50	48	47	45	44	42	41	41	40	39	38	38	37	36	36	35	34	33	33	32	31	30	29	
22									79	111	139	125	121	120	126	146	150	129	120	114	102	91	84	78	78	77	82	87	83	79	71	62	58	56	52	50	48	46	45	44	43	42	42	41	40	39	38	38	36	35	35	34	33	32	31	30	30
21									97	120	128	124	120	118	125	139	127	123	110	110	98	88	83	77	75	75	78	83	80	78	72	65	63	61	58	56	55	51	49	48	46	45	44	46	43	42	40	39	38	37	36	35	34	33	32	33	30
20									87	116	118	122	120	117	122	129	130	131	116	102	94	86	81	75	72	69	71	79	78	77	73	68	66	67	64	61	59	56	54	51	50	48	47	46	45	44	42	41	40	39	37	36	35	34	32	31	
19									81	101	119	114	117	119	123	136	141	125	108	95	89	81	76	72	69	66	70	75	73	72	70	68	69	70	68	66	64	62	61	60	57	56	53	52	50	48	46	44	43	41	40	38	36	34	33		
18		33	37	39	43	47	55	63	76	90	103	117	120	112	135	147	130	113	101	89	85	77	72	60	65	65	67	71	69	67	68	68	70	73	72	71	70	69	68	68	66	61	59	57	55	53	50	48	46	44	42	40	38	35			
17		34	34	39	43	47	53	60	71	81	95	105	116	127	134	141	125	109	94	84	77	71	67	64	62	60	63	67	65	63	64	64	66	68	68	68	69	69	70	71	69	67	66	65	63	61	57	54	52	50	47	44	43				
16	32	33	34	39	42	46	57	57	65	73	83	94	113	131	133	135	120	104	91	78	72	66	63	60	59	58	60	62	63	59	60	60	62	63	64	64	67	69	72	75	74	72	73	73	70	66	65	61	59	57	55	49					
15	31	32	35	37	40	44	49	53	60	67	76	85	103	121	124	128	112	94	84	72	64	60	58	56	56	55	57	59	57	55	56	56	57	56	59	60	62	64	66	69	69	68	68	68	66	64	63	61	59	58	55	52					
14	31	32	34	35	39	42	46	50	54	62	69	77	93	110	116	121	104	87	77	67	60	54	54	53	53	55	54	56	54	52	52	52	53	53	54	55	57	56	61	66	64	64	64	64	62	61	60	60	60	59	57	55					
13	31	32	33	34	37	40	46	47	52	57	64	71	87	104	107	109	95	80	72	64	59	53	52	50	50	50	52	53	52	50	50	50	51	51	52	53	54	53	57	59	59	60	59	59	57	55	54	56	53	52	50	48					
12	31	31	32	32	36	39	42	45	49	53	59	66	82	87	98	98	86	74	68	62	57	52	50	48	47	47	49	50	49	48	48	48	49	49	50	51	52	52	56	55	55	55	54	53	51	49	48	47	46	45	45						
11	31	31	32	32	34	37	40	45	47	50	56	62	75	86	86	86	77	70	66	62	58	54	53	49	48	47	48	49	48	47	48	48	48	48	49	50	51	52	53	54	54	54	53	51	49	47	46	45									
10	31	31	32	32	33	34	37	41	44	48	53	59	68	78	74	70	68	65	63	62	58	55	53	50	49	47	48	48	47	47	47	47	48	48	48	49	51	52	52	53	52	52	51	49	47	45	44	42									
9		31	32	32	33	34	36	38	41	44	49	55	61	67	66	64	62	60	59	59	56	54	52	49	48	47	49	51	51	51	50	50	50	50	50	50	52	54	54	55	55	54	53	51	48	46	46	42									
8		31	31	32	32	33	34	36	38	41	44	50	54	57	57	58	56	54	55	57	54	52	50	49	48	47	50	53	54	54	54	53	52	52	52	53	54	56	56	57	57	57	55	53	50	47	44										
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6		31	31	31	32	32	33	34	35	37	39	41	42	44	45	44	46	44	46	46	46	43	43	42	42	42	44	46	47	48	49	50	50	51	51	50	49	48	48	47	48	49	50	50	50	49	47										
5																																				45	44	44	43	43	43	44	45	45	46	48	42										
4																																										39	40	41	41												

in 1999

	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
30																														46	44	43	39	35	32	30	30	29	29	29																	
29													99	108	124	151	172	167	149	116	111	107	94	81	74	66	62	58	54	49	47	45	41	38	35	33	32	31	30	29	29	29	29														
28													110	117	134	172	192	204	166	127	125	174	108	91	81	72	67	63	58	55	50	47	44	41	39	37	35	33	31	29	29	29	29	29	29	29	28	28									
27													125	128	143	178	201	236	189	144	143	141	121	101	90	79	75	70	65	59	55	51	48	44	42	40	38	36	35	33	32	32	31	30	29	29	28	28	28	28							
26									122	125	128	136	138	140	155	186	207	247	180	163	160	158	135	112	99	88	82	77	71	65	60	55	51	47	45	43	41	40	38	36	35	35	33	32	30	29	28	28	28	28	28	28	28				
25									132	143	159	136	149	153	168	184	218	238	175	154	156	154	132	110	104	97	94	89	81	73	66	60	55	51	49	46	45	43	41	40	39	39	37	36	35	33	33	32	32	32	31	31	30	30	29	28	
24									136	134	213	172	168	173	178	191	233	229	174	161	156	151	130	109	110	111	106	101	91	80	72	66	60	55	52	50	48	47	45	45	43	42	41	40	39	38	37	37	36	35	34	34	33	31	30	28	
23									133	147	200	175	177	176	186	208	230	180	148	152	145	134	119	104	105	105	106	107	99	91	81	71	66	60	58	55	53	50	49	47	46	46	46	45	42	41	40	39	38	37	36	35	34	32	33	30	
22									129	147	187	164	139	138	144	197	203	172	140	151	135	118	109	100	100	99	107	114	108	103	89	77	71	65	63	60	57	56	53	53	50	49	48	46	45	44	43	42	40	38	38	37	35	34	32	31	30
21									126	159	170	143	157	155	163	187	169	145	144	146	129	115	106	98	96	93	100	107	106	100	91	82	79	75	72	68	65	61	59	56	55	53	52	50	49	48	46	44	42	41	40	38	37	35	33	32	31
20									115	153	155	141	137	156	142	172	186	177	155	155	125	112	104	96	92	87	94	101	100	96	92	86	86	85	81	76	72	68	65	62	60	57	56	55	53	51	49	46	45	43	42	40	38	36	34	33	
19									104	132	157	150	155	157	163	185	190	167	144	125	115	105	98	91	87	83	89	95	93	91	89	86	88	89	86	83	80	78	76	76	70	66	64	62	60	58	54	51	49	47	45	43	40	37	35		
18		38	41	44	50	55	66	78	96	115	135	174	158	163	161	198	174	150	133	116	107	90	91	83	82	78	84	90	87	85	85	86	89	93	92	90	89	87	86	85	80	75	72	70	67	64	60	56	53	50	48	45	42	38			
17		34	40	43	49	54	64	73	88	103	120	138	153	169	179	190	167	144	124	108	99	90	85	79	72	74	79	84	83	79	79	80	85	84	86	86	87	88	89	95	87	84	82	81	78	75	71	66	63	60	56	57	47				
16	33	35	39	43	48	53	61	69	80	91	106	121	148	175	178	181	159	130	119	100	91	82	78	73	72	71	74	78	75	73	76	73	77	78	80	82	85	88	92	96	94	92	92	93	87	86	81	76	73	69	64	59					
15	33	34	37	41	45	50	57	64	73	83	96	109	135	140	165	171	148	125	108	92	83	76	71	69	68	67	70	73	70	68	68	69	70	71	73	75	77	80	84	88	87	86	84	86	84	81	78	75	73	71	67	63					
14	32	33	34	38	45	47	55	58	67	75	86	97	121	143	153	161	136	112	98	85	74	65	65	64	64	63	66	69	66	62	63	63	64	65	66	67	69	71	75	79	80	80	80	80	78	75	75	75	76	73	70	66					
13	32	33	34	36	41	45	50	55	62	69	79	89	112	136	140	144	123	102	91	79	72	66	62	60	60	59	62	64	62	60	60	60	61	62	63	64	66	67	70	73	73	74	73	72	70	67	66	65	66	62	59	56					
12	32	33	35	34	38	43	47	51	57	63	72	83	104	127	127	127	110	93	84	76	69	62	59	56	55	55	58	60	59	57	57	58	58	59	60	61	62	63	65	67	67	67	66	65	62	59	57	55	54	52	49						
11	32	33	33	34	37	40	44	48	54	60	66	76	93	113	110	107	97	87	82	76	70	65	61	58	56	55	57	59	57	54	56	57	57	57	59	60	61	63	64	65	65	65	63	62	59	56	54	52									
10	32	32	33	33	35	36	41	45	51	56	64	72	85	99	93	86	84	81	78	75	71	67	63	60	57	55	56	57	54	53	55	56	56	56	57	58	61	63	63	64	63	63	61	59	56	53	51	49									
9		32	33	33	34	35	39	42	46	51	58	65	73	84	81	79	76	73	72	72	68	65	62	58	57	55	58	61	61	60	60	60	60	59	60	61	63	66	66	67	66	66	64	61	58	54	51	48									
8		32	32	33	34	35	37	39	42	46	55	59	64	69	69	70	67	65	66	68	65	62	60	57	56	54	60	65	65	66	65	64	63	62	62	63	66	69	69	69	70	70	67	64	59	55	51										
7		32	32	33	33	34	36	38	40	43	48	53	56	60	61	62	60	59	60	60	58	56	54	52	52	52	56	59	60	61	62	62	62	62	61	61	62	63	63	63	63	64	63	62	59	57	53										
6		32	32	32	33	33	35	36	38	40	43	46	48	50	52	54	53	53	53	53	51	50	49	48	48	48	51	54	55	57	58	59	60	61	60	60	58	57	57	56	57	58	59	60	60	59	55										
5																																				53	52	51	50	50	50	51	52	53	53	53	49										
4																																										44	45	46	47												

Table 3-2(3) Average Annual NO_x Concentrations in Samut Prakarn Province in the Case of Taking No Countermeasures for Emission Sources (Unit: 0.1 PPb)

in 1992

[illegible]

in 1999

[illegible]

Table 3-3 Number of Mesh by Rank of Air Pollutant Concentration (Case of Taking No Countermeasures)

(SO_2)

Rank of cocentra-tion (ppb)	Number of mesh		
	1988	1992	1999
0.0~ 5.0	977	929	885
5.0~10.0	128	154	150
10.0~15.0	28	42	67
15.0~20.0	21	16	24
20.0~25.0	5	14	13
25.0~30.0	0	4	13
30.0~35.0	0	0	6
35.0~40.0	0	0	1
TOTAL	1159	1159	1159

(NO_2)

Rank of cocentra-tion (ppb)	Number of mesh		
	1988	1992	1999
0.0~ 5.0	674	476	300
5.0~ 7.5	305	429	437
7.5~10.0	109	104	190
10.0~12.5	64	93	68
12.5~15.0	7	46	55
15.0~17.5	0	10	68
17.5~20.0	0	1	28
20.0~22.5	0	0	7
22.5~25.0	0	0	6
TOTAL	1159	1159	1159

(NO_x)

Rank of cocentra-tion (ppb)	Number of mesh		
	1988	1992	1999
0.0~ 5.0	277	223	169
5.0~10.0	676	643	544
10.0~15.0	116	141	228
15.0~20.0	79	92	68
20.0~25.0	9	51	68
25.0~30.0	2	7	61
30.0~35.0	0	1	13
35.0~40.0	0	1	6
40.0~45.0	0	0	0
45.0~50.0	0	0	1
50.0~55.0	0	0	1
TOTAL	1159	1159	1159

Table 3-4 Number of Mesh at Which Environmental Standards Are Exceeded (Case of Taking No Countermeasures)

Year	SO_2	NO_2
1988	0	0
1992	0	0
1999	0	31

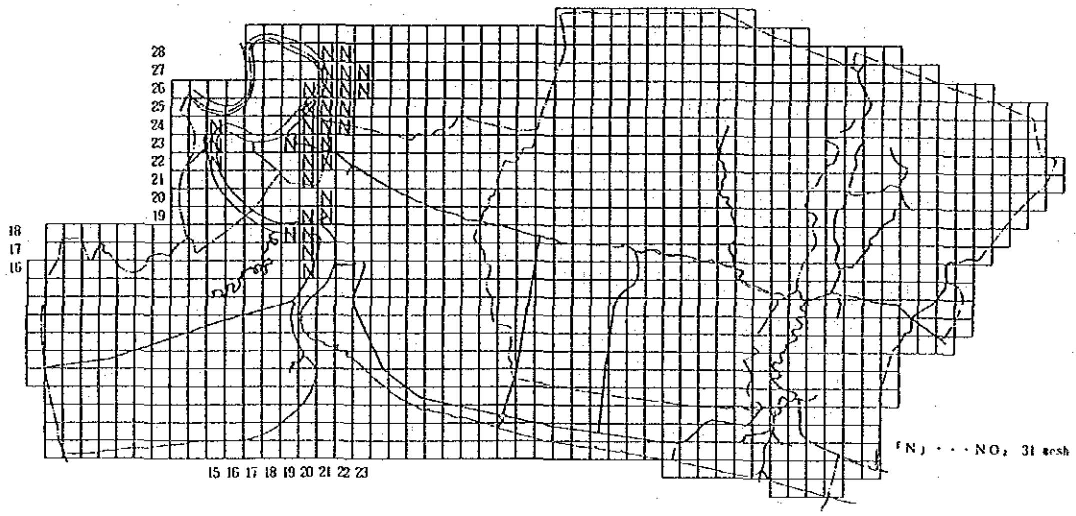


Fig. 3-2 Points Where NO_2 Environmental Standards Are Exceeded in Samut Prakarn Prefecture (Case of Taking No Countermeasures, in 1999)

Table 3-5(1) Contributive Concentration by Emission Sources at High SO_2 Concentration Points (Case of Taking No Countermeasures, in 1992)

(Rank 1 IX,IY=16,24)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	75	1	4.499	16.8
	2)	3	111	2	0.956	3.6
	3)	3	4	1	0.929	3.5
	4)	3	69	1	0.537	2.0
	5)	3	52	2	0.449	1.7
	6)	3	5	1	0.439	1.6
	7)	3	14	1	0.426	1.6
	8)	3	14	2	0.426	1.6
	9)	3	98	5	0.421	1.6
	10)	3	14	3	0.418	1.6
	Remaining stacks				5.896	22.0
	Sub total				15.396	57.3
Factory (area source)					7.169	26.7
Factory (industrial estate)					0.006	0.0
Roadways					1.141	4.2
Vessels (sailing)					2.790	10.4
Ferryboats (anchoring)					0.035	0.1
Ferryboats (sailing)					0.212	0.8
Back ground					0.100	0.4
TOTAL					26.849	100.0

(Rank 2 IX,IY=16,23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	75	1	3.067	11.6
	2)	3	4	1	0.979	3.7
	3)	3	111	2	0.844	3.2
	4)	3	47	3	0.769	2.9
	5)	3	52	2	0.670	2.5
	6)	3	69	1	0.644	2.4
	7)	3	47	1	0.592	2.2
	8)	3	47	2	0.592	2.2
	9)	3	14	1	0.501	1.9
	10)	3	14	2	0.501	1.9
	Remaining stacks				6.353	24.1
	Sub total				15.512	58.9
Factory (area source)					7.568	28.7
Factory (industrial estate)					0.009	0.0
Roadways					1.203	4.6
Vessels (sailing)					1.763	6.7
Ferryboats (anchoring)					0.024	0.1
Ferryboats (sailing)					0.159	0.6
Back ground					0.100	0.4
TOTAL					26.338	100.0

(Rank 3 IX,IY=17,23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	111	2	2.336	9.1
	2)	3	111	3	1.139	4.5
	3)	3	14	1	1.013	4.0
	4)	3	14	2	1.013	4.0
	5)	3	14	3	0.972	3.8
	6)	3	1	2	0.741	2.9
	7)	3	69	1	0.696	2.7
	8)	3	111	4	0.631	2.5
	9)	3	98	5	0.540	2.1
	10)	3	75	1	0.529	2.1
	Remaining stacks				5.488	21.5
	Sub total				15.098	59.1
Factory (area source)					7.155	28.0
Factory (industrial estate)					0.012	0.0
Roadways					1.303	5.1
Vessels (sailing)					1.860	7.3
Ferryboats (anchoring)					0.005	0.0
Ferryboats (sailing)					0.034	0.1
Back ground					0.100	0.4
TOTAL					25.567	100.0

(Rank 4 IX,IY=15,23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	75	1	1.543	6.1
	2)	3	47	3	1.207	4.8
	3)	3	47	1	0.916	3.6
	4)	3	47	2	0.916	3.6
	5)	3	5	1	0.647	2.6
	6)	3	111	2	0.467	1.8
	7)	3	59	2	0.413	1.6
	8)	3	4	1	0.383	1.5
	9)	3	98	5	0.353	1.4
	10)	3	54	1	0.341	1.3
	Remaining stacks				6.253	24.7
	Sub total				13.439	53.1
Factory (area source)					5.787	22.9
Factory (industrial estate)					0.006	0.0
Roadways					0.970	3.8
Vessels (sailing)					2.694	10.7
Ferryboats (anchoring)					0.278	1.1
Ferryboats (sailing)					2.012	8.0
Back ground					0.100	0.4
TOTAL					25.286	100.0

(Rank 5 IX,IY=17,24)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	111	2	1.347	5.6
	2)	3	14	1	1.113	4.6
	3)	3	14	2	1.113	4.6
	4)	3	14	3	1.072	4.5
	5)	3	75	1	0.964	4.0
	6)	3	4	1	0.939	3.9
	7)	3	1	2	0.550	2.3
	8)	3	69	1	0.500	2.1
	9)	3	98	5	0.464	1.9
	10)	3	13	1	0.400	1.7
	Remaining stacks				5.473	22.7
	Sub total				13.935	57.9
Factory (area source)					6.656	27.6
Factory (industrial estate)					0.009	0.0
Roadways					1.165	4.8
Vessels (sailing)					2.152	8.9
Ferryboats (anchoring)					0.007	0.0
Ferryboats (sailing)					0.051	0.2
Back ground					0.100	0.4
TOTAL					24.075	100.0

(Rank 6 IX,IY=15,22)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	47	3	1.016	4.3
	2)	3	75	1	0.845	3.5
	3)	3	47	1	0.594	2.5
	4)	3	47	2	0.594	2.5
	5)	3	111	2	0.568	2.4
	6)	3	51	2	0.550	2.3
	7)	3	51	3	0.492	2.1
	8)	3	54	1	0.491	2.1
	9)	3	54	2	0.418	1.8
	10)	3	54	3	0.418	1.8
	Remaining stacks				6.328	26.6
	Sub total				12.314	51.7
Factory (area source)					6.472	27.2
Factory (industrial estate)					0.009	0.0
Roadways					1.119	4.7
Vessels (sailing)					2.638	11.1
Ferryboats (anchoring)					0.075	0.3
Ferryboats (sailing)					1.104	4.6
Back ground					0.100	0.4
TOTAL					23.831	100.0

(Rank 7 IX,IY=15,21)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	47	3	1.299	5.6
	2)	3	47	1	0.890	3.9
	3)	3	47	2	0.890	3.9
	4)	3	111	2	0.485	2.1
	5)	3	75	1	0.382	1.7
	6)	3	5	1	0.350	1.5
	7)	3	95	2	0.322	1.4
	8)	3	54	1	0.269	1.2
	9)	3	14	3	0.249	1.1
	10)	3	14	1	0.248	1.1
	Remaining stacks				6.150	26.6
	Sub total				11.534	49.9
Factory (area source)					7.338	31.8
Factory (industrial estate)					0.010	0.0
Roadways					1.131	4.9
Vessels (sailing)					2.666	11.5
Ferryboats (anchoring)					0.029	0.1
Ferryboats (sailing)					0.287	1.2
Back ground					0.100	0.4
TOTAL					23.095	100.0

(Rank 8 IX,IY=18,23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	14	3	1.319	5.7
	2)	3	14	1	1.106	4.8
	3)	3	14	2	1.106	4.8
	4)	3	8	1	0.923	4.0
	5)	3	16	1	0.735	3.2
	6)	3	16	2	0.735	3.2
	7)	3	111	2	0.657	2.8
	8)	3	3	1	0.517	2.2
	9)	3	16	4	0.510	2.2
	10)	3	98	5	0.508	2.2
	Remaining stacks				5.983	25.9
	Sub total				14.099	61.1
Factory (area source)					6.004	26.0
Factory (industrial estate)					0.014	0.1
Roadways					1.361	5.9
Vessels (sailing)					1.480	6.4
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.015	0.1
Back ground					0.100	0.4
TOTAL					23.075	100.0

Table 3-5(2) Contributive Concentration by Emission Sources at High NO_2 Concentration Points (Case of Taking No Countermeasures, in 1992)

(Rank 1 IX, IY=22, 26)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.064	0.4
	2)	3	98	3	0.038	0.2
	3)	3	98	4	0.034	0.2
	4)	3	105	2	0.028	0.2
	5)	3	98	1	0.024	0.1
	6)	3	98	2	0.024	0.1
	7)	3	105	1	0.018	0.1
	8)	1	39	1	0.008	0.0
	9)	1	70	2	0.006	0.0
	10)	1	70	1	0.005	0.0
	Remaining stacks				0.080	0.4
	Sub total				0.329	1.8
Factory (area source)					0.185	1.0
Factory(industrial estate)					0.002	0.0
Roadways					14.234	79.0
Vessels (sailing)					0.444	2.5
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.019	0.1
Back ground					2.800	15.5
TOTAL					18.015	100.0

(Rank 2 IX, IY=22, 25)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.060	0.3
	2)	3	98	3	0.037	0.2
	3)	3	98	4	0.032	0.2
	4)	3	105	2	0.030	0.2
	5)	3	98	1	0.024	0.1
	6)	3	98	2	0.024	0.1
	7)	3	105	1	0.019	0.1
	8)	1	39	1	0.011	0.1
	9)	1	70	2	0.007	0.0
	10)	1	70	1	0.005	0.0
	Remaining stacks				0.091	0.5
	Sub total				0.340	2.0
Factory (area source)					0.217	1.2
Factory(industrial estate)					0.002	0.0
Roadways					13.606	78.2
Vessels (sailing)					0.410	2.4
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.016	0.1
Back ground					2.800	16.1
TOTAL					17.393	100.0

(Rank 5 IX, IY=21, 23)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.057	0.3
	2)	3	105	2	0.038	0.2
	3)	3	98	3	0.036	0.2
	4)	3	98	4	0.030	0.2
	5)	3	98	1	0.026	0.2
	6)	3	98	2	0.026	0.2
	7)	3	105	1	0.026	0.2
	8)	1	39	1	0.011	0.1
	9)	1	70	2	0.008	0.0
	10)	1	70	1	0.006	0.0
	Remaining stacks				0.135	0.8
	Sub total				0.399	2.4
Factory (area source)					0.309	1.8
Factory(industrial estate)					0.002	0.0
Roadways					12.880	76.3
Vessels (sailing)					0.473	2.8
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.014	0.1
Back ground					2.800	16.6
TOTAL					16.879	100.0

(Rank 6 IX, IY=22, 24)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.054	0.3
	2)	3	98	3	0.033	0.2
	3)	3	105	2	0.030	0.2
	4)	3	98	4	0.029	0.2
	5)	3	98	1	0.022	0.1
	6)	3	98	2	0.022	0.1
	7)	3	105	1	0.020	0.1
	8)	1	39	1	0.016	0.1
	9)	1	70	2	0.008	0.0
	10)	1	70	1	0.006	0.0
	Remaining stacks				0.107	0.6
	Sub total				0.347	2.1
Factory (area source)					0.234	1.4
Factory(industrial estate)					0.002	0.0
Roadways					12.989	77.5
Vessels (sailing)					0.382	2.3
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.012	0.1
Back ground					2.800	16.7
TOTAL					16.768	100.0

(Rank 3 IX, IY=22, 27)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.064	0.4
	2)	3	98	3	0.038	0.2
	3)	3	98	4	0.034	0.2
	4)	3	105	2	0.027	0.2
	5)	3	98	1	0.023	0.1
	6)	3	98	2	0.023	0.1
	7)	3	105	1	0.017	0.1
	8)	1	39	1	0.006	0.0
	9)	1	70	2	0.005	0.0
	10)	1	70	1	0.004	0.0
	Remaining stacks				0.074	0.4
	Sub total				0.315	1.8
Factory (area source)					0.158	0.9
Factory(industrial estate)					0.001	0.0
Roadways					13.460	78.1
Vessels (sailing)					0.473	2.7
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.022	0.1
Back ground					2.800	16.2
TOTAL					17.232	100.0

(Rank 4 IX, IY=21, 24)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.068	0.4
	2)	3	98	3	0.042	0.2
	3)	3	105	2	0.038	0.2
	4)	3	98	4	0.036	0.2
	5)	3	98	2	0.029	0.2
	6)	3	98	1	0.028	0.2
	7)	3	105	1	0.025	0.1
	8)	1	39	1	0.010	0.1
	9)	1	70	2	0.007	0.0
	10)	1	70	1	0.006	0.0
	Remaining stacks				0.128	0.7
	Sub total				0.417	2.4
Factory (area source)					0.331	1.9
Factory(industrial estate)					0.002	0.0
Roadways					12.980	76.0
Vessels (sailing)					0.524	3.1
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.017	0.1
Back ground					2.800	16.4
TOTAL					17.073	100.0

(Rank 7 IX, IY=21, 25)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.074	0.5
	2)	3	98	3	0.045	0.3
	3)	3	98	4	0.040	0.2
	4)	3	105	2	0.036	0.2
	5)	3	98	1	0.029	0.2
	6)	3	98	2	0.029	0.2
	7)	3	105	1	0.023	0.1
	8)	1	39	1	0.009	0.1
	9)	1	70	2	0.006	0.0
	10)	1	70	1	0.005	0.0
	Remaining stacks				0.110	0.7
	Sub total				0.406	2.5
Factory (area source)					0.290	1.8
Factory(industrial estate)					0.002	0.0
Roadways					11.888	74.1
Vessels (sailing)					0.630	3.9
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.022	0.1
Back ground					2.800	17.5
TOTAL					16.041	100.0

(Rank 8 IX, IY=15, 24)

	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.103	0.7
	2)	3	98	3	0.064	0.4
	3)	3	98	4	0.055	0.4
	4)	3	105	2	0.045	0.3
	5)	3	98	1	0.042	0.3
	6)	3	98	2	0.042	0.3
	7)	3	105	1	0.031	0.2
	8)	3	75	1	0.028	0.2
	9)	3	5	1	0.023	0.1
	10)	3	118	1	0.011	0.1
	Remaining stacks				0.192	1.2
	Sub total				0.536	4.1
Factory (area source)					0.600	3.9
Factory(industrial estate)					0.000	0.0
Roadways					4.760	30.8
Vessels (sailing)					1.813	11.7
Ferryboats (anchoring)					0.734	4.8
Ferryboats (sailing)					4.096	26.5
Back ground					2.800	18.1
TOTAL					15.439	100.0

Table 3-5(3) Contributive Concentration by Emission Sources at High SO_2 Concentration Points (Case of Taking No Countermeasures, in 1999)

(Rank 1 IX, IY=16,24)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	75	1	5.987	17.0
	2)	3	111	2	1.170	3.3
	3)	3	4	1	1.155	3.3
	4)	3	69	1	0.686	1.9
	5)	3	14	1	0.604	1.7
	6)	3	14	2	0.604	1.7
	7)	3	52	2	0.562	1.6
	8)	3	47	3	0.527	1.5
	9)	3	118	2	0.510	1.4
	10)	3	98	5	0.501	1.4
	Remaining stacks				7.763	22.0
	Sub total				20.069	56.9
Factory (area source)					9.563	27.1
Factory (industrial estate)					0.006	0.0
Roadways					1.410	4.0
Vessels (sailing)					3.721	10.6
Ferryboats (anchoring)					0.056	0.2
Ferryboats (sailing)					0.333	0.9
Back ground					0.100	0.3
TOTAL					35.258	100.0

(Rank 2 IX, IY=16,23)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	75	1	4.072	12.0
	2)	3	4	1	1.176	3.5
	3)	3	111	2	0.987	2.9
	4)	3	47	3	0.954	2.8
	5)	3	52	2	0.797	2.3
	6)	3	69	1	0.774	2.3
	7)	3	47	1	0.730	2.1
	8)	3	47	2	0.730	2.1
	9)	3	14	1	0.693	2.0
	10)	3	14	2	0.693	2.0
	Remaining stacks				8.133	23.9
	Sub total				19.739	57.9
Factory (area source)					10.095	29.6
Factory (industrial estate)					0.009	0.0
Roadways					1.486	4.4
Vessels (sailing)					2.351	6.9
Ferryboats (anchoring)					0.037	0.1
Ferryboats (sailing)					0.249	0.7
Back ground					0.100	0.3
TOTAL					34.066	100.0

(Rank 3 IX, IY=15,23)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	75	1	2.055	6.1
	2)	3	47	3	1.509	4.5
	3)	3	47	1	1.140	3.4
	4)	3	47	2	1.140	3.4
	5)	3	5	2	0.683	2.0
	6)	3	111	2	0.573	1.7
	7)	3	59	2	0.524	1.6
	8)	3	5	1	0.521	1.5
	9)	3	4	1	0.485	1.4
	10)	3	54	1	0.447	1.3
	Remaining stacks				8.522	25.2
	Sub total				17.599	52.1
Factory (area source)					7.719	22.8
Factory (industrial estate)					0.006	0.0
Roadways					1.199	3.5
Vessels (sailing)					3.594	10.6
Ferryboats (anchoring)					0.436	1.3
Ferryboats (sailing)					3.151	9.3
Back ground					0.100	0.3
TOTAL					33.804	100.0

(Rank 4 IX, IY=17,23)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	111	2	2.769	8.5
	2)	3	111	3	1.395	4.3
	3)	3	14	1	1.262	3.9
	4)	3	14	2	1.262	3.9
	5)	3	1	2	0.988	3.0
	6)	3	69	1	0.821	2.5
	7)	3	14	3	0.819	2.5
	8)	3	111	4	0.785	2.4
	9)	3	75	1	0.704	2.2
	10)	3	98	5	0.633	2.0
	Remaining stacks				7.180	22.1
	Sub total				18.618	57.4
Factory (area source)					9.544	29.4
Factory (industrial estate)					0.012	0.0
Roadways					1.610	5.0
Vessels (sailing)					2.480	7.6
Ferryboats (anchoring)					0.007	0.1
Ferryboats (sailing)					0.053	0.2
Back ground					0.100	0.3
TOTAL					32.424	100.0

(Rank 5 IX, IY=15,22)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	47	3	1.195	3.8
	2)	3	75	1	1.128	3.6
	3)	3	51	2	0.733	2.3
	4)	3	47	1	0.723	2.3
	5)	3	47	2	0.723	2.3
	6)	3	111	2	0.700	2.2
	7)	3	51	3	0.656	2.1
	8)	3	54	1	0.624	2.0
	9)	3	54	2	0.531	1.7
	10)	3	54	3	0.531	1.7
	Remaining stacks				8.187	26.2
	Sub total				15.729	50.4
Factory (area source)					8.633	27.7
Factory (industrial estate)					0.009	0.0
Roadways					1.383	4.4
Vessels (sailing)					3.519	11.3
Ferryboats (anchoring)					0.117	0.4
Ferryboats (sailing)					1.729	5.5
Back ground					0.100	0.3
TOTAL					31.219	100.0

(Rank 6 IX, IY=17,24)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	111	2	1.630	5.2
	2)	3	14	1	1.503	4.8
	3)	3	14	2	1.503	4.8
	4)	3	75	1	1.284	4.1
	5)	3	4	1	1.156	3.7
	6)	3	14	3	0.884	2.8
	7)	3	1	2	0.734	2.4
	8)	3	69	1	0.636	2.0
	9)	3	98	5	0.552	1.8
	10)	3	13	1	0.520	1.7
	Remaining stacks				7.270	23.4
	Sub total				17.672	56.9
Factory (area source)					8.878	28.6
Factory (industrial estate)					0.009	0.0
Roadways					1.440	4.6
Vessels (sailing)					2.870	9.2
Ferryboats (anchoring)					0.011	0.0
Ferryboats (sailing)					0.079	0.3
Back ground					0.100	0.3
TOTAL					31.059	100.0

(Rank 7 IX, IY=15,21)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	47	3	1.554	5.2
	2)	3	47	1	1.062	3.5
	3)	3	47	2	1.062	3.5
	4)	3	111	2	0.607	2.0
	5)	3	75	1	0.509	1.7
	6)	3	95	2	0.421	1.4
	7)	3	14	1	0.372	1.2
	8)	3	14	2	0.372	1.2
	9)	3	5	2	0.371	1.2
	10)	3	54	1	0.342	1.1
	Remaining stacks				8.140	27.0
	Sub total				14.812	49.1
Factory (area source)					9.788	32.5
Factory (industrial estate)					0.010	0.0
Roadways					1.398	4.6
Vessels (sailing)					3.556	11.8
Ferryboats (anchoring)					0.045	0.1
Ferryboats (sailing)					0.450	1.5
Back ground					0.100	0.3
TOTAL					30.159	100.0

(Rank 8 IX, IY=18,23)

	Type of source SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	14	1	1.413	4.8
	2)	3	14	2	1.413	4.8
	3)	3	8	1	1.176	4.0
	4)	3	14	3	1.104	3.7
	5)	3	16	1	0.981	3.3
	6)	3	16	2	0.981	3.3
	7)	3	111	2	0.767	2.6
	8)	3	16	4	0.681	2.3
	9)	3	3	1	0.663	2.3
	10)	3	16	3	0.595	2.0
	Remaining stacks				7.874	26.7
	Sub total				17.648	59.9
Factory (area source)					8.009	27.2
Factory (industrial estate)					0.014	0.0
Roadways					1.682	5.7
Vessels (sailing)					1.974	6.7
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.023	0.1
Back ground					0.100	0.3
TOTAL					29.453	100.0

Table 3-5(4) Contributive Concentration by Emission Sources at High NO_2 Concentration Points (Case of Taking No Countermeasures, in 1999)

(Rank 1 IX, IY=22, 26)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.078	0.3
	2)	3	98	3	0.047	0.2
	3)	3	98	4	0.042	0.2
	4)	3	98	1	0.030	0.1
	5)	3	98	2	0.030	0.1
	6)	3	105	2	0.023	0.1
	7)	3	105	3	0.023	0.1
	8)	3	105	1	0.015	0.1
	9)	1	39	1	0.011	0.0
	10)	1	70	2	0.008	0.0
	Remaining stacks				0.113	0.5
	Sub total				0.420	1.7
Factory (area source)					0.247	1.0
Factory (industrial estate)					0.002	0.0
Roadways					20.612	83.4
Vessels (sailing)					0.592	2.4
Ferryboats (anchoring)					0.004	0.0
Ferryboats (sailing)					0.029	0.1
Back ground					2.800	11.3
TOTAL					24.706	100.0

(Rank 2 IX, IY=22, 25)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.073	0.3
	2)	3	98	3	0.044	0.2
	3)	3	98	4	0.039	0.2
	4)	3	98	2	0.030	0.1
	5)	3	98	1	0.029	0.1
	6)	3	105	2	0.024	0.1
	7)	3	105	3	0.024	0.1
	8)	3	105	1	0.016	0.1
	9)	1	39	1	0.015	0.1
	10)	1	70	2	0.009	0.0
	Remaining stacks				0.128	0.5
	Sub total				0.431	1.8
Factory (area source)					0.289	1.2
Factory (industrial estate)					0.002	0.0
Roadways					19.702	82.8
Vessels (sailing)					0.547	2.3
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.024	0.1
Back ground					2.800	11.8
TOTAL					23.798	100.0

(Rank 5 IX, IY=21, 23)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.066	0.3
	2)	3	98	3	0.041	0.2
	3)	3	98	4	0.035	0.2
	4)	3	105	2	0.032	0.1
	5)	3	105	3	0.032	0.1
	6)	3	98	2	0.031	0.1
	7)	3	98	1	0.030	0.1
	8)	3	105	1	0.022	0.1
	9)	1	39	1	0.014	0.1
	10)	1	70	2	0.010	0.0
	Remaining stacks				0.185	0.8
	Sub total				0.498	2.2
Factory (area source)					0.412	1.8
Factory (industrial estate)					0.002	0.0
Roadways					18.651	81.0
Vessels (sailing)					0.631	2.7
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.021	0.1
Back ground					2.800	12.2
TOTAL					23.018	100.0

(Rank 6 IX, IY=22, 24)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.065	0.3
	2)	3	98	3	0.039	0.2
	3)	3	98	4	0.034	0.1
	4)	3	98	1	0.027	0.1
	5)	3	98	2	0.027	0.1
	6)	3	105	2	0.025	0.1
	7)	3	105	3	0.025	0.1
	8)	1	39	1	0.021	0.1
	9)	3	105	1	0.016	0.1
	10)	1	70	2	0.010	0.0
	Remaining stacks				0.150	0.7
	Sub total				0.439	1.9
Factory (area source)					0.313	1.4
Factory (industrial estate)					0.002	0.0
Roadways					18.808	82.2
Vessels (sailing)					0.509	2.2
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.020	0.1
Back ground					2.800	12.2
TOTAL					22.893	100.0

(Rank 3 IX, IY=22, 27)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.080	0.3
	2)	3	98	3	0.048	0.2
	3)	3	98	4	0.043	0.2
	4)	3	98	1	0.030	0.1
	5)	3	98	2	0.030	0.1
	6)	3	105	2	0.022	0.1
	7)	3	105	3	0.022	0.1
	8)	3	105	1	0.014	0.1
	9)	1	39	1	0.008	0.0
	10)	1	70	2	0.007	0.0
	Remaining stacks				0.100	0.4
	Sub total				0.404	1.7
Factory (area source)					0.211	0.9
Factory (industrial estate)					0.001	0.0
Roadways					19.490	82.7
Vessels (sailing)					0.630	2.7
Ferryboats (anchoring)					0.004	0.0
Ferryboats (sailing)					0.034	0.1
Back ground					2.800	11.9
TOTAL					23.574	100.0

(Rank 4 IX, IY=21, 24)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.081	0.3
	2)	3	98	3	0.049	0.2
	3)	3	98	4	0.043	0.2
	4)	3	98	1	0.035	0.2
	5)	3	98	2	0.035	0.2
	6)	3	105	2	0.031	0.1
	7)	3	105	3	0.031	0.1
	8)	3	105	1	0.021	0.1
	9)	1	39	1	0.013	0.1
	10)	1	70	2	0.009	0.0
	Remaining stacks				0.177	0.8
	Sub total				0.525	2.3
Factory (area source)					0.441	1.9
Factory (industrial estate)					0.002	0.0
Roadways					18.796	80.7
Vessels (sailing)					0.698	3.0
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.026	0.1
Back ground					2.800	12.0
TOTAL					23.291	100.0

(Rank 7 IX, IY=21, 25)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.090	0.4
	2)	3	98	3	0.054	0.2
	3)	3	98	4	0.048	0.2
	4)	3	98	1	0.036	0.2
	5)	3	98	2	0.036	0.2
	6)	3	105	2	0.029	0.1
	7)	3	105	3	0.029	0.1
	8)	3	105	1	0.019	0.1
	9)	1	39	1	0.011	0.1
	10)	1	70	2	0.008	0.0
	Remaining stacks				0.154	0.7
	Sub total				0.514	2.4
Factory (area source)					0.387	1.8
Factory (industrial estate)					0.002	0.0
Roadways					17.214	79.0
Vessels (sailing)					0.841	3.9
Ferryboats (anchoring)					0.004	0.0
Ferryboats (sailing)					0.034	0.2
Back ground					2.800	12.8
TOTAL					21.796	100.0

(Rank 8 IX, IY=15, 24)

Type of source	SEQ)	Coun ty	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.125	0.6
	2)	3	98	3	0.077	0.4
	3)	3	98	4	0.067	0.3
	4)	3	98	1	0.053	0.2
	5)	3	98	2	0.052	0.2
	6)	3	105	2	0.037	0.2
	7)	3	105	3	0.037	0.2
	8)	3	75	1	0.037	0.2
	9)	3	105	1	0.025	0.1
	10)	3	5	2	0.023	0.1
	Remaining stacks				0.280	1.3
	Sub total				0.813	3.8
Factory (area source)					0.800	3.8
Factory (industrial estate)					0.000	0.0
Roadways					6.892	32.4
Vessels (sailing)					2.418	11.4
Ferryboats (anchoring)					1.150	5.4
Ferryboats (sailing)					6.415	30.1
Back ground					2.800	13.2
TOTAL					21.288	100.0

4. Remedical Efforts against Emission Source Improvements and their Effectiveness

It was clarified that the atmospheric NO_2 concentration in Samut Prakarn Province would exceed the environmental standards in 1999 and that cars would occupy most of the contribution rates by emission source at the points where the said NO_2 concentration would exceed the standard. Then, with cars as a target, specific remedial measures for NO_2 emission sources (such as adoption of NO_x emission controlled cars) were studied, coupled with forecast of the ambient concentration of NO_2 after adoption of restricted cars.

Although it was predicted that the ambient concentration of SO_2 would not exceed the environmental standard despite the progress of economic and social development, the contribution rates at high concentration points would be greatly occupied by factories. Thus, this led to forecast of the extent to which the environment would be improved if SO_2 emission control is implemented for factories in future.

4.1 SO_2 Emission Control for Factories

At present, no SO_2 emission control is in force in Thailand. In other words, it is presently permissible no matter how much SO_2 may be emitted. This leads to lack of fairness among factories, suggesting that some measure should be taken. Thus, environmental remedy was examined in case that K-value control of Japan was adopted as a specific control measure for emission sources for factories with 1999 as the target year. This K-value control is the control of maximum concentration on the ground level as shown in the equation (4-1), which can be met by either making stacks higher or reducing SO_2 emission volume. Specific K value was established making reference to that of an area of Japan similar to Samut Prakarn Province.

$$K = \frac{q}{He^2} \times 10^3 \qquad \text{(4-1)}$$

where q is the quantity of sulfur oxide and He is the effective stack height calculated from equations (4-2) and (4-3).

$$He = H_o + 0.65\,(Hm + Ht) \qquad \text{(4-2)}$$

$$\left.\begin{aligned} Hm &= \frac{0.795\sqrt{Q\cdot V}}{1+\dfrac{2.58}{V}} \\ H_t &= 2.01\times 10^{-3}\cdot Q\cdot (T-288)\cdot\left\{2.30\log J + \frac{1}{J} - 1\right\} \\ J &= \frac{1}{\sqrt{Q\cdot V}}\left\{1460 - 296\times\frac{V}{T-288}\right\} + 1 \end{aligned}\right\} \qquad \text{(4-3)}$$

where

H_e : effective stack height (m)
H_o : actual stack height (m)
Q : exhaust gas volume at 15°C (m^3/s)
V : discharge speed of exhaust gas (m/s)
T : temperature of exhaust gas (°K)

4.1.1 Establishment of the K Value

Table 4-1 shows the volume of SO_2 per area emitted from factories in Samut Prakarn province, and Table 4-2 shows those from factories in the regions of Japan which are similar to the foregoing province. These data indicate that in the Samut Prakarn region the SO_2 volume per area is 19.52 tons/year/km^2, whereas in Japan the SO_2 volume obtained by averaging those regions with a K value of 13.0 accounts for 11.72 tons/year/km^2. Likewise, those regions with a K value of 10.0 give an average volume of 9.06 tons/year/km^2, and those with 8.0 have an average of 8.37 tons/year/km^2. As a consequence, K=13.0 is considered most suitable to be applied to the Samut Prakarn region judging from the emission volume of SO_2 per area. Looking at the K values in Table 4-2, the volume of SO_2 per area greatly varies among prefectures and cities even though they have the same K value. This is because the K value in Japan is determined based on the considerations including not only the density of factories and the scope of smoke diffusion, but also the feasibility of administrative control.

Table 4-1 SO_2 Volume per Area Emitted from Factories in Samut Prakarn Province during 1988

Name of county	① SO_2 emission volume (ton/y)	② Area (km^2)	③=①÷② SO_2 volume per area (ton/y/km^2)
1 Muang	5163	356	14.50
2 Bang Plee	932	534	1.75
3 Phra Pradaeng	12235	49	249.69
TOTAL	18330	939	19.52

Table 4-2 SO_2 Volume per Area Emitted from Factories in the Regions of Japan Similar to Samut Prakarn

K value	Name of city	Yearly average SO_2 concentration in 1987 (ppb)	① SO_2 emission volume in 1985 (ton/y)	② Area (km^2)	①÷② SO_2 emission volume per area (ton/y/km^2)
13.0	Shibukawa	9	1373.6	51.84	26.50
	Numazu	7	452.0	151.20	2.99
	Mishima	5	1043.2	61.81	16.88
	Tamano	10	180.7	103.35	1.75
	Komatsujima	7	1093.3	44.38	24.63
	Naruto	6	730.6	135.41	5.40
	Anan	7	4608.3	252.83	18.23
	Kurume	7	1675.1	123.93	13.52
	Itoman	2	249.9	44.98	5.56
	Okinawa	3	86.9	48.74	1.78
10.0	Kushiro	11	5417.5	218.85	24.75
	Takefu	5	446.1	184.98	2.41
	Sabae	9	386.0	84.23	4.58
	Saseho	5	1123.7	250.46	4.49
8.0	Otaru	9	504.5	244.65	2.06
	Asahikawa	8	1877.7	749.42	2.51
	Sakata	4	1358.9	175.00	7.77
	Utsunomiya	8	1024.8	312.53	3.28
	Kanuma	6	229.2	311.74	0.74
	Mouka	6	891.5	111.49	8.00
	Tsuruga	6	1262.9	249.51	5.06
	Takehara	8	5464.7	117.54	46.49
	Mihara	10	1349.8	204.35	6.61
	Onomichi	8	125.9	110.73	1.14

Remark : The reason why difference of SO_2 emission volume is seen at the areas adopted the same K-value is due to institutional judgement social-economical factors.

Table 4-3 shows actual stack heights required to achieve the K values (8.0, 10.0, 13.0). Suppose the K value is 13.0, except for extremely low stacks with an actual stack height of around 5 m, it is sufficient to add to the stack heights of 10 to 15 m to reach about 20 m, and this is thought to be the most feasible in view of economic efficiency.

Based on the above consideration, the concept of K value control in Japan was adopted for the control of SO_2 emission from factories in Samut Prakarn province, and the specific K value was thought to be 13.0.

4.1.2 SO_2 and NO_x Emission Volume after Implementation of SO_2 Emission Control

In implementing K-value control, the K-value may be satisfied either by increasing stack height as described above, or reducing the emission volume of SO_2. This allowed us to compute an actual stack height and an SO_2 emission volume required to fulfill K=13. The results are shown in Table 4-4. According to these results, some factories would have to cut back their current emission volumes of SO_2 to about 1/7 if they attempt to achieve the K-value by reducing the emission volume. Since that would be impossible, the other alternative of increasing stack heights was thought to be realistic to achieve the K-value.

It should be kept in mind that a higher stack will not expand the scope of pollution; if emission volumes are same, *the ground level concentration of a pollutant emitted from a high altitude will* no doubt be lowered compared with that from a low altitude under an identical diffusion condition. That is to say, Fig. 4-1 shows axial ground level concentrations on the down wind distance (CU/Q) in a single stack when the effective stack height He is varied, indicating that higher stacks exhibit lower ground level concentrations in any leeward distances as compared with lower stacks.

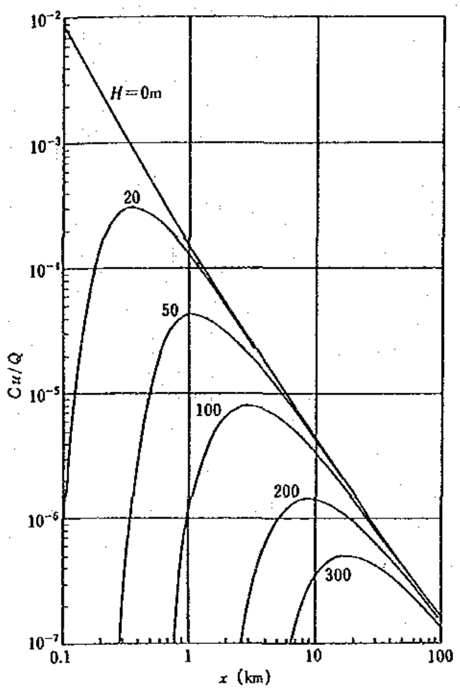


Fig. 4-1 ***Axial ground level concentration for different effective stacks*** **heights He (u; wind speed, Q; emission volume)**

Table 4-3 Stack Heights Required to Acheive K Values (13.0, 10.0 and 8.0)

SEQ)	Coun ty code	Fac- tory No.	Sta- ck No.	K value	Actual stack height H_o (m)	Gas velo- city V(m/s)	Gas tempe- rature T (°K)	Normal Exhaust gas volume Q (m^3/s)	Normal SO_2 Emission volume q(Nm^3/h)	Effec- tive stack height He (m)	Actual stack height based on K-value (m) K=13	K=10	K=8
1)	3	75	1	90.039	5	0.00	313	26.092	31.697	18.76	35.6	42.5	49.2
2)	3	34	3	67.761	5	0.00	350	2.935	5.610	9.10	16.7	19.6	22.4
3)	2	23	4	42.609	5	0.00	350	2.697	3.231	8.78	12.1	14.3	16.5
4)	1	68	2	34.269	20	6.09	462	6.712	28.970	29.08	38.1	44.8	51.1
5)	3	23	5	30.064	5	0.00	333	4.349	2.633	9.36	9.9	11.9	13.8
6)	3	24	1	29.116	7	4.46	462	0.350	1.812	7.89	10.9	12.6	14.2
7)	2	24	2	27.290	2	7.58	437	0.157	0.186	2.61	3.2	3.7	4.2
8)	3	96	1	26.888	5	0.00	350	5.849	4.548	13.01	10.7	13.3	15.8
9)	3	33	2	26.734	6	0.00	437	0.007	0.971	6.03	8.6	9.8	11.0
10)	1	39	1	25.701	15	0.00	462	2.940	18.078	26.52	25.8	31.0	36.0
11)	2	19	2	25.591	6	0.00	523	0.519	2.019	8.88	9.6	11.3	13.0
12)	3	97	1	25.134	5	0.00	318	0.125	0.652	5.09	7.0	8.0	8.9
13)	1	68	1	25.125	15	2.64	462	1.860	8.047	17.90	22.0	25.5	28.8
14)	1	66	1	24.422	10	0.00	453	1.570	6.206	15.94	15.9	19.0	21.9
15)	3	59	2	24.260	10	0.00	443	1.852	6.647	16.55	16.1	19.2	22.3
16)	3	111	2	23.762	22	9.32	496	6.119	24.545	32.14	33.3	39.4	45.3
17)	1	56	2	20.636	6	0.00	448	1.482	2.703	11.45	9.0	11.0	12.9
18)	3	14	1	20.192	20	15.30	483	4.587	16.464	28.55	27.0	32.0	36.8
19)	3	14	2	20.192	20	15.30	483	4.587	16.464	28.55	27.0	32.0	36.8
20)	3	109	2	19.581	12	0.00	462	0.926	4.858	15.75	15.6	18.3	20.9
21)	3	90	1	19.235	10	0.00	462	0.932	3.649	13.77	13.0	15.3	17.6
22)	1	70	3	19.096	6	0.00	437	1.639	2.567	11.59	8.5	10.4	12.3
23)	1	35	2	18.772	15	5.69	483	1.305	5.895	17.72	18.6	21.6	24.4
24)	3	54	1	18.708	16	0.00	448	1.864	9.730	22.81	20.5	24.4	28.1
25)	1	35	1	18.651	15	5.69	483	1.305	5.857	17.72	18.5	21.5	24.3
26)	3	16	4	18.528	15	0.00	473	1.813	9.512	22.66	19.4	23.2	26.8
27)	3	102	1	18.359	13	0.00	462	2.319	9.008	22.15	17.2	20.9	24.4
28)	1	68	3	17.797	20	2.03	462	2.237	9.657	23.29	24.0	27.8	31.4
29)	1	66	2	17.647	14	0.00	453	2.223	8.796	22.33	17.7	21.3	24.8
30)	3	16	3	16.988	15	0.00	473	1.449	7.608	21.16	18.0	21.4	24.7
31)	3	47	3	16.855	12	0.00	498	2.025	7.922	21.68	15.0	18.5	21.8
32)	1	2	1	16.752	12	0.00	473	1.778	6.381	19.52	14.6	17.7	20.7
33)	3	109	1	16.244	15	0.00	462	1.237	6.478	19.97	17.4	20.5	23.5
34)	1	64	1	16.110	10	0.00	462	0.667	2.609	12.73	11.4	13.4	15.3
35)	1	70	2	15.533	18	38.04	573	5.406	16.113	32.21	21.0	25.9	30.7
36)	3	5	2	14.924	24	34.79	523	9.631	27.299	42.77	27.1	33.5	39.6
37)	3	16	1	14.734	15	0.00	473	1.086	5.692	19.65	16.3	19.2	22.0
38)	3	16	2	14.734	15	0.00	473	1.086	5.692	19.65	16.3	19.2	22.0
39)	1	70	1	14.690	18	30.38	573	4.317	12.890	29.62	19.9	24.3	28.5
40)	3	54	2	14.540	18	0.00	473	1.864	9.730	25.87	19.5	23.3	27.0
41)	3	54	3	14.540	18	0.00	473	1.864	9.730	25.87	19.5	23.3	27.0
42)	3	110	2	14.309	10	12.61	462	0.556	1.994	11.81	10.6	12.3	14.0
43)	2	5	6	14.268	10	0.00	462	0.608	2.226	12.49	10.6	12.4	14.2
44)	3	28	1	14.122	10	0.00	462	0.445	1.979	11.84	10.5	12.2	13.9
45)	1	55	1	13.881	30	0.00	393	4.230	22.098	39.90	31.3	37.1	42.7
46)	1	55	2	13.881	30	0.00	393	4.230	22.098	39.90	31.3	37.1	42.7
47)	3	14	3	13.771	20	7.65	483	2.293	8.232	24.45	20.7	24.2	27.6
48)	1	64	2	13.344	6	0.00	462	0.196	0.622	6.83	6.1	7.1	8.0
49)	3	95	2	13.218	7	0.00	333	1.141	0.886	8.19	7.1	8.2	9.3
50)	3	36	1	12.723	15	0.00	448	1.037	4.521	18.85	—	17.4	19.9

Table 4-4 Actual Stack Heights and SO_2 Emission Volumes Required to Fulfill K=13.0

STACK SEQ)	STACK Coun ty code	STACK Fac- tory No.	STACK Sta- ck No.	K value	Actual stack height H_o (m)	Gas velo- city V(m/s)	Gas tempe- rature T (°K)	Normal Exhaust gas volume Q (m^3/s)	Normal SO_2 Emission volume q(Nm^3/h)	Effec- tive stack height He (m)	Actual stack height & Normal SO_2 volume sui- table for K=13 H_o (m)	q(Nm^3/h)
1)	3	75	1	90.039	5	0.00	313	26.092	31.697	18.76	35.6	4.576
2)	3	34	3	67.761	5	0.00	350	2.935	5.610	9.10	16.7	1.076
3)	2	23	4	42.609	5	0.00	350	2.697	3.281	8.78	12.1	1.001
4)	1	68	2	34.269	20	6.09	462	6.712	28.970	29.08	38.1	10.990
5)	3	23	5	30.064	5	0.00	333	4.349	2.633	9.36	9.9	1.139
6)	3	24	1	29.116	7	4.46	462	0.350	1.812	7.89	10.9	0.809
7)	2	24	2	27.290	2	7.58	437	0.157	0.186	2.61	3.2	0.089
8)	3	96	1	26.888	5	0.00	350	5.849	4.548	13.01	10.7	2.199
9)	3	33	2	26.734	6	0.00	437	0.007	0.971	6.03	8.6	0.472
10)	1	39	1	25.701	15	0.00	462	2.940	18.078	26.52	25.8	9.144
11)	2	19	2	25.591	6	0.00	523	0.519	2.019	8.88	9.6	1.026
12)	3	97	1	25.134	5	0.00	318	0.125	0.652	5.09	7.0	0.337
13)	1	68	1	25.125	15	2.64	462	1.860	8.047	17.90	22.0	4.164
14)	1	66	1	24.422	10	0.00	453	1.570	6.206	15.94	15.9	3.303
15)	3	59	2	24.260	10	0.00	443	1.852	6.647	16.55	16.1	3.562
16)	3	111	2	23.762	22	9.32	496	6.119	24.545	32.14	33.3	13.428
17)	1	56	2	20.636	6	0.00	448	1.482	2.703	11.45	9.0	1.703
18)	3	14	1	20.192	20	15.30	483	4.587	16.464	28.55	27.0	10.600
19)	3	14	2	20.192	20	15.30	483	4.587	16.464	28.55	27.0	10.600
20)	3	109	2	19.581	12	0.00	462	0.926	4.858	15.75	15.6	3.225
21)	3	90	1	19.235	10	0.00	462	0.932	3.649	13.77	13.0	2.466
22)	1	70	3	19.096	6	0.00	437	1.639	2.567	11.59	8.5	1.748
23)	1	35	2	18.772	15	5.69	483	1.305	5.895	17.72	18.6	4.082
24)	3	54	1	18.708	16	0.00	448	1.864	9.730	22.81	20.5	6.761
25)	1	35	1	18.651	15	5.69	483	1.305	5.857	17.72	18.5	4.082
26)	3	16	4	18.528	15	0.00	473	1.813	9.512	22.66	19.4	6.574
27)	3	102	1	18.359	13	0.00	462	2.319	9.008	22.15	17.2	6.379
28)	1	68	3	17.797	20	2.03	462	2.237	9.657	23.29	24.0	7.054
29)	1	66	2	17.647	14	0.00	453	2.223	8.796	22.33	17.7	6.480
30)	3	16	3	16.988	15	0.00	473	1.449	7.608	21.16	18.0	5.822
31)	3	47	3	16.855	12	0.00	498	2.025	7.922	21.68	15.0	6.110
32)	1	2	1	16.752	12	0.00	473	1.778	6.381	19.52	14.6	4.952
33)	3	109	1	16.244	15	0.00	462	1.237	6.478	19.97	17.4	5.184
34)	1	64	1	16.110	10	0.00	462	0.667	2.609	12.73	11.4	2.105
35)	1	70	2	15.533	18	38.04	573	5.406	16.113	32.21	21.0	13.485
36)	3	5	2	14.924	24	34.79	523	9.631	27.299	42.77	27.1	23.780
37)	3	16	1	14.734	15	0.00	473	1.086	5.692	19.65	16.3	5.022
38)	3	16	2	14.734	15	0.00	473	1.086	5.692	19.65	16.3	5.022
39)	1	70	1	14.690	18	30.38	573	4.317	12.890	29.62	19.9	11.407
40)	3	54	2	14.540	18	0.00	473	1.864	9.730	25.87	19.5	8.699
41)	3	54	3	14.540	18	0.00	473	1.864	9.730	25.87	19.5	8.699
42)	3	110	2	14.309	10	12.61	462	0.556	1.994	11.81	10.6	1.812
43)	2	5	6	14.268	10	0.00	462	0.608	2.226	12.49	10.6	2.028
44)	3	28	1	14.122	10	0.00	462	0.445	1.979	11.84	10.5	1.822
45)	1	55	1	13.881	30	0.00	393	4.230	22.098	39.90	31.3	20.695
46)	1	55	2	13.881	30	0.00	393	4.230	22.098	39.90	31.3	20.695
47)	3	14	3	13.771	20	7.65	483	2.293	8.232	24.45	20.7	7.771
48)	1	64	2	13.344	6	0.00	462	0.196	0.622	6.83	6.1	0.606
49)	3	95	2	13.218	7	0.00	333	1.141	0.886	8.19	7.1	0.871
50)	3	36	1	12.723	15	0.00	448	1.037	4.521	18.85	—	—

Thus, SO_2 emission volume after improvement of K-value control is same as that when no source countermeasure is taken, showing 29,442 tons/year as presented in Fig. 2-1(1) and Table 2-1. In addition, the emission volume of NO_x also remains unchanged because of no improvement in combustion plants, amounting to 14,052 tons/year as exhibited in Fig. 2-1(2) and Table 2-1.

In order to achieve the K value, in addition to increasing the stack height to enhance He, another way is to reduce the caliber of stack and increase gas ejection velocity, thus having greater He. In the case of a stack with umbrella, in addition, the ejection velocity will be raised if the umbrella is removed, so that the stack height will not have to be increased more than necessary. Therefore, taking into consideration economic efficiency as will be described in Part VII, the stack caliber was made smaller to have a gas ejection velocity of 15 m/s, coupled with a limited stack height. Table 4-5 shows the results of the above measures.

Table 4-5 Improvements in Factory Stacks

STACK				Actual stack height (m)		Diameter (m)		Gas velocity (m/s)	
SEQ)	County code	Factory No.	Stack No.	before count.	after count.	before count.	after count.	before count.	after count.
1)	3	75	1	5	38.0	9.9	1.55	0.00	15.0
2)	3	34	3	5	17.0	9.9	0.55	0.00	15.0
3)	2	23	4	5	12.5	9.9	0.53	0.00	15.0
4)	1	68	2	20	37.0	1.5	0.96	6.09	15.0
5)	3	23	5	5	10.0	9.9	0.65	0.00	15.0
6)	3	24	1	7	10.5	0.4	0.22	4.46	15.0
7)	2	24	2	2	3.0	0.2	0.14	7.58	15.0
8)	3	96	1	5	13.0	9.9	0.78	0.00	15.0
9)	3	33	2	6	8.5	0.6	0.03	0.00	15.0
10)	1	39	1	15	31.5	0.5	0.63	0.00	15.0
11)	2	19	2	6	10.5	1.2	0.28	0.00	15.0
12)	3	97	1	5	6.5	9.9	0.11	0.00	15.0
13)	1	68	1	15	21.0	1.2	0.50	2.64	15.0
14)	1	66	1	10	18.5	0.4	0.46	0.00	15.0
15)	3	59	2	10	19.0	0.7	0.49	0.00	15.0
16)	3	111	2	22	33.0	1.2	0.95	9.32	15.0
17)	1	56	2	6	11.0	0.6	0.44	0.00	15.0
18)	3	14	1	20	27.5	0.8	0.81	15.30	15.0
19)	3	14	2	20	27.5	0.8	0.81	15.30	15.0
20)	3	109	2	12	17.0	0.4	0.36	0.00	15.0
21)	3	90	1	10	14.5	0.8	0.36	0.00	15.0
22)	1	70	3	6	10.5	1.7	0.46	0.00	15.0
23)	1	35	2	15	18.0	0.7	0.43	5.69	15.0
24)	3	54	1	16	23.5	0.6	0.50	0.00	15.0
25)	1	35	1	15	18.0	0.7	0.43	5.69	15.0
26)	3	16	4	15	23.0	0.6	0.50	0.00	15.0
27)	3	102	1	13	21.5	0.5	0.56	0.00	15.0
28)	1	68	3	20	22.5	1.5	0.55	2.03	15.0
29)	1	66	2	14	21.5	0.6	0.54	0.00	15.0
30)	3	16	3	15	20.5	0.6	0.45	0.00	15.0
31)	3	47	3	12	20.0	0.7	0.55	0.00	15.0
32)	1	2	1	12	18.0	0.6	0.50	0.00	15.0
33)	3	109	1	15	19.5	0.5	0.41	0.00	15.0
34)	1	64	1	10	12.0	0.5	0.30	0.00	15.0
35)	1	70	2	18	23.5	0.6	0.96	38.04	15.0
36)	3	5	2	24	29.5	0.8	1.22	34.79	15.0
37)	3	16	1	15	18.0	0.6	0.39	0.00	15.0
38)	3	16	2	15	18.0	0.6	0.39	0.00	15.0
39)	1	70	1	18	21.5	0.6	0.85	30.38	15.0
40)	3	54	2	18	23.0	0.9	0.51	0.00	15.0
41)	3	54	3	18	23.0	0.9	0.51	0.00	15.0
42)	3	110	2	10	10.5	0.3	0.28	12.61	15.0
43)	2	5	6	10	11.5	0.5	0.29	0.00	15.0
44)	3	28	1	10	11.0	0.4	0.25	0.00	15.0
45)	1	55	1	30	35.5	0.6	0.70	0.00	15.0
46)	1	55	2	30	35.5	0.6	0.70	0.00	15.0
47)	3	14	3	20	20.0	0.8	0.57	7.65	15.0
48)	1	64	2	6	6.0	0.3	0.16	0.00	15.0
49)	3	95	2	7	7.0	0.3	0.33	0.00	15.0

4.2 Adoption of NO_x Emission Restricted Cars

In Samut Prakarn province it is predicted that the ambient concentration of NO_2 will exceed the environmental NO_2 standard in 1999, mostly attributable to automobiles (with a contribution rate of about 80%). As a consequence, automobile exhaust control will be required to fulfill the environmental control standard of NO_2 in future years.

Table 4-6 shows NO_x emission factors by auto emission restriction yuear established by the Ministry of Construction of Japan. While the NO_x emission factors of this table are classified by 6 vehicle types, Table 4-7 shows NO_x emission factors made correspondent with the 5-type classification in Thailand (see Part IV, 3, 4). Table 4-8 shows the reduction rate of the NO_x emission volume from automobiles in each year when NO_x emission restriction is adopted from 1973, using the NO_x emission factors shown in Table 4-7 as well as the composition of cars by type, traffic volume by road, and car speed in Samut Prakarn province. On the other hand, the reduction rate of contributory concentration by cars, which is required to lower the concentrations of NO_2 at the points where they will exceed NO_2 environmental standard in 1999 down to NO_2 environmental standard value (18 ppb) by instituting NO_x restricted cars, are figured out as shown Table 4-9, revealing that a 47.9% reduction is necessary. Because of the proportional relationship between the NO_x emission volume and the NO_2 diffusion concentration, the reduction rates of NO_x emission volume in 1999 is computed as 47.9%. If these reduction rates are allowed to match the NO_x reduction rates when restricted cars are adopted (Table 4-8), it is understandable that adoption of 1978 controlled cars by Japan will be required in 1999 to accomplish NO_2 environmental standard. Table 4-10 shows the automobile emission volumes of NO_x in Samut Prakarn province due to the adoption of restricted cars, and Fig. 4-2 shows NO_x emission volume by mesh.

Table 4-6 NO_x Emission Factors by Year of Automobile Emission Restriction (Established by the Ministry of Contruction in Japan)

Vehicle type in JAPAN	Section velocity	Restriction year non	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	unit
Passenger car	10 km/h	2.62	2.58	←	1.38	0.87	←	0.30	←	←	←	←	←	
	20 km/h	2.54	2.16	←	1.13	0.73	←	0.25	←	←	←	←	←	
	30 km/h	2.82	2.12	←	1.08	0.72	←	0.25	←	←	←	←	←	
	40 km/h	3.15	2.13	←	1.06	0.73	←	0.25	←	←	←	←	←	
	50 km/h	3.48	2.11	←	1.02	0.73	←	0.25	←	←	←	←	←	(g/km/car)
	60 km/h	3.75	2.04	←	0.95	0.70	←	0.24	←	←	←	←	←	
	80 km/h	4.65	2.61	←	1.29	1.28	←	0.44	←	←	←	←	←	
	100 km/h	4.63	3.63	←	2.54	2.65	←	0.90	←	←	←	←	←	
Light cargo vehicle	10 km/h	6.98	4.19	←	2.97	←	←	←	1.98 1.65	← ←	1.49 0.99	← ←	← ←	(g/km/car)
	20 km/h	5.59	3.45	←	2.46	←	←	←	1.64 1.37	← ←	1.23 0.82	← ←	← ←	
	30 km/h	5.26	3.34	←	2.39	←	←	←	1.59 1.33	← ←	1.20 0.80	← ←	← ←	
	40 km/h	5.04	3.29	←	2.37	←	←	←	1.58 1.32	← ←	1.19 0.79	← ←	← ←	left...middle class (1.7~2.5ton)
	50 km/h	4.74	3.20	←	2.32	←	←	←	1.55 1.29	← ←	1.16 0.77	← ←	← ←	
	60 km/h	4.27	3.02	←	2.20	←	←	←	1.47 1.23	← ←	1.10 0.73	← ←	← ←	
	80 km/h	4.98	4.61	←	3.49	←	←	←	2.32 1.94	← ←	1.74 1.16	← ←	← ←	right...light class (1.7ton or less)
	100 km/h	8.03	7.44	←	5.64	←	←	←	3.76 3.14	← ←	2.82 1.88	← ←	← ←	
Heavy duty gasoline vehicle	10 km/h	7.25	5.60	←	←	←	4.72	←	3.35	←	←	2.29	←	
	20 km/h	6.04	4.67	←	←	←	3.94	←	2.79	←	←	1.91	←	
	30 km/h	5.92	4.58	←	←	←	3.86	←	2.74	←	←	1.87	←	
	40 km/h	5.92	4.58	←	←	←	3.86	←	2.74	←	←	1.87	←	
	50 km/h	5.84	4.52	←	←	←	3.81	←	2.70	←	←	1.84	←	(g/km/car)
	60 km/h	5.60	4.34	←	←	←	3.65	←	2.59	←	←	1.77	←	
	80 km/h	7.54	5.83	←	←	←	4.92	←	3.49	←	←	2.38	←	
	100 km/h	8.68	6.72	←	←	←	5.67	←	4.02	←	←	2.75	←	
Diesel vehicle (Direct fuel injection)	10 km/h	2.074 13.90	← ←	1.665 11.16	← ←	← ←	1.406 9.42	← ←	1.168 7.82	← ←	← ←	← ←	1.016 6.81	
	20 km/h	1.654 11.08	← ←	1.362 9.13	← ←	← ←	1.150 7.70	← ←	0.955 6.40	← ←	← ←	← ←	0.831 5.57	
	30 km/h	1.550 10.38	← ←	1.309 8.77	← ←	← ←	1.105 7.40	← ←	0.918 6.15	← ←	← ←	← ←	0.799 5.35	
	40 km/h	1.478 9.90	← ←	1.284 8.60	← ←	← ←	1.084 7.26	← ←	0.900 6.03	← ←	← ←	← ←	0.783 5.25	
	50 km/h	1.381 9.25	← ←	1.240 8.31	← ←	← ←	1.046 7.01	← ←	0.869 5.82	← ←	← ←	← ←	0.756 5.07	
	60 km/h	1.237 8.29	← ←	1.157 7.75	← ←	← ←	0.977 6.54	← ←	0.811 5.44	← ←	← ←	← ←	0.706 4.73	
	80 km/h	1.143 7.66	← ←	0.984 6.59	← ←	← ←	0.830 5.56	← ←	0.690 4.62	← ←	← ←	← ←	0.600 4.02	
	100 km/h	1.864 12.49	← ←	1.079 7.23	← ←	← ←	0.911 6.10	← ←	0.756 5.07	← ←	← ←	← ←	0.658 4.41	
Diesel vehicle (non-direct fuel injection)	10 km/h	1.185 5.21	← ←	1.013 4.46	← ←	← ←	0.855 3.76	← ←	0.766 3.37	← ←	← ←	0.653 2.87	← ←	
	20 km/h	1.019 4.48	← ←	0.872 3.84	← ←	← ←	0.736 3.24	← ←	0.659 2.90	← ←	← ←	0.561 2.47	← ←	left (g/km/car/ton)
	30 km/h	1.027 4.52	← ←	0.878 3.87	← ←	← ←	0.741 3.26	← ←	0.664 2.92	← ←	← ←	0.566 2.49	← ←	
	40 km/h	1.057 4.65	← ←	0.904 3.98	← ←	← ←	0.763 3.36	← ←	0.684 3.01	← ←	← ←	0.582 2.56	← ←	
	50 km/h	1.075 4.73	← ←	0.920 4.05	← ←	← ←	0.776 3.42	← ←	0.695 3.06	← ←	← ←	0.592 2.61	← ←	
	60 km/h	1.067 4.69	← ←	0.913 4.02	← ←	← ←	0.770 3.39	← ←	0.690 3.04	← ←	← ←	0.588 2.59	← ←	right (g/km/car)
	80 km/h	1.489 6.55	← ←	1.274 5.61	← ←	← ←	1.075 4.73	← ←	0.963 4.24	← ←	← ←	0.820 3.61	← ←	
	100 km/h	1.933 8.51	← ←	1.654 7.28	← ←	← ←	1.396 6.14	← ←	1.250 5.50	← ←	← ←	1.065 4.69	← ←	
Diesel vehicle (Swirl chamber type)	10 km/h	0.889 1.78	← ←	0.852 1.70	← ←	← ←	0.719 1.44	← ←	0.644 1.29	← ←	← ←	0.548 1.10	← ←	
	20 km/h	0.776 1.55	← ←	0.743 1.49	← ←	← ←	0.627 1.25	← ←	0.562 1.12	← ←	← ←	0.479 0.96	← ←	
	30 km/h	0.792 1.58	← ←	0.759 1.52	← ←	← ←	0.640 1.28	← ←	0.574 1.15	← ←	← ←	0.489 0.98	← ←	
	40 km/h	0.825 1.65	← ←	0.791 1.58	← ←	← ←	0.667 1.33	← ←	0.598 1.20	← ←	← ←	0.509 1.02	← ←	
	50 km/h	0.850 1.70	← ←	0.814 1.63	← ←	← ←	0.687 1.37	← ←	0.616 1.23	← ←	← ←	0.524 1.05	← ←	
	60 km/h	0.855 1.71	← ←	0.819 1.64	← ←	← ←	0.691 1.38	← ←	0.619 1.24	← ←	← ←	0.528 1.06	← ←	
	80 km/h	1.148 2.30	← ←	1.099 2.20	← ←	← ←	0.928 1.86	← ←	0.831 1.66	← ←	← ←	0.708 1.42	← ←	
	100 km/h	1.489 2.98	← ←	1.427 2.85	← ←	← ←	1.204 2.41	← ←	1.079 2.16	← ←	← ←	0.919 1.84	← ←	

Table 4-7 NO_x Emission Factors by Year of Automobile Emission Restriction Based on 5-Type Classification in Thailand

(unit:g/km/car)

Vehicle type in Thailand	Section Velocity	Restriction year non	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Light vehicle	10km/h	2.75	2.05	2.01	1.70	Same as left	1.55	Same as left	1.18	Same as left	1.03	0.93	Same as left
	20km/h	2.27	1.74	1.70	1.45		1.32		1.01		0.89	0.80	
	30km/h	2.21	1.73	1.69	1.45		1.32		1.01		0.90	0.80	
	40km/h	2.19	1.75	1.71	1.48		1.34		1.04		0.92	0.82	
	50km/h	2.14	1.76	1.72	1.50		1.35		1.05		0.93	0.83	
	60km/h	2.03	1.72	1.68	1.47		1.33		1.03		0.93	0.82	
	80km/h	2.54	2.44	2.39	2.11		1.91		1.47		1.30	1.16	
	100km/h	3.68	3.54	3.47	3.02		2.76		2.00		1.80	1.62	
Heavy vehicle	10km/h	11.12	Same as left	9.81	Same as left	Same as left	8.23	Same as left	7.33	Same as left	Same as left	6.41	6.26
	20km/h	9.49		8.41			7.10		6.29			5.49	5.37
	30km/h	9.49		8.46			7.14		6.33			5.52	5.41
	40km/h	9.70		8.69			7.33		6.50			5.66	5.55
	50km/h	9.79		8.82			7.44		6.60			5.74	5.63
	60km/h	9.64		8.73			7.36		6.53			5.69	5.58
	80km/h	12.68		11.37			9.60		8.54			7.38	7.29
	100km/h	16.83		14.57			12.30		10.96			9.44	9.35
Gasoline	10km/h	2.62	2.58	Same as left	1.38	0.87	Same as left	0.30	Same as left	Same as left	Same as left	Same as left	Same as left
	20km/h	2.54	2.16		1.13	0.73		0.25					
	30km/h	2.82	2.12		1.08	0.72		0.25					
	40km/h	3.15	2.13		1.06	0.73		0.25					
	50km/h	3.48	2.11		1.02	0.73		0.25					
	60km/h	3.75	2.04		0.95	0.70		0.24					
	80km/h	4.65	2.61		1.29	1.28		0.44					
	100km/h	4.63	3.63		2.54	2.65		0.90					
LPG	10km/h	3.21	2.49	Same as left	1.39	0.78	Same as left	0.29	Same as left	Same as left	Same as left	Same as left	Same as left
	20km/h	3.11	2.09		1.14	0.65		0.24					
	30km/h	3.45	2.05		1.09	0.64		0.24					
	40km/h	3.85	2.06		1.07	0.65		0.24					
	50km/h	4.26	2.04		1.03	0.65		0.24					
	60km/h	4.59	1.97		0.96	0.62		0.23					
	80km/h	5.69	2.52		1.30	1.14		0.42					
	100km/h	5.66	3.51		2.57	2.36		0.86					
Motor cycle	10km/h	0.26	0.26	Same as left	0.14	0.09	Same as left	0.03	Same as left	Same as left	Same as left	Same as left	Same as left
	20km/h	0.25	0.22		0.11	0.07		0.03					
	30km/h	0.28	0.21		0.11	0.07		0.03					
	40km/h	0.32	0.21		0.11	0.07		0.03					
	50km/h	0.35	0.21		0.10	0.07		0.03					
	60km/h	0.38	0.20		0.10	0.07		0.02					
	80km/h	0.47	0.26		0.13	0.13		0.04					
	100km/h	0.46	0.36		0.25	0.27		0.09					

Table 4-8 Reduction Rate of NO_x Emission Volume due to Adoption of Restricted Cars

Restriction year	Cut percent of NOx emisson volume (%)
non restriction	0.00
1973	15.74
1974	21.25
1975	33.24
1976	36.52
1977	44.64
1978	49.25
1979	55.84
1980	55.84
1981	56.67
1982	61.82
1983	62.38

Table 4-9 Reduction Rates of Automobile Contributory Concentration Required to Achieve NO_2 Environmental Standard in 1999

Mesh code	NO_2 Concentration (ppb)	Environmental standard value (ppb)	Reduction in concentration (ppb) *Pb)	Automobile contributory concentration (ppb)	Automobile contributory concentration required to achieve environmental standard (ppb)	Reduction rate of automobile contributory concentration (%)
20- 16-0	18.1	18.0	0.1	12.95	12.85	0.8
20- 17-0	19.0	18.0	1.0	13.98	12.98	7.2
19- 18-0	18.1	18.0	0.1	13.13	13.03	0.8
20- 18-0	19.8	18.0	1.8	15.00	13.20	12.0
20- 19-0	18.5	18.0	0.5	13.72	13.22	3.6
21- 19-0	19.0	18.0	1.0	14.58	13.58	6.9
21- 20-0	18.6	18.0	0.6	14.13	13.83	4.2
20- 21-0	18.7	18.0	0.7	14.26	13.56	4.9
15- 22-0	18.7	18.0	0.7	8.86	8.16	7.9
20- 22-0	19.7	18.0	1.7	15.15	13.45	11.2
21- 22-0	20.3	18.0	2.3	16.07	13.77	14.3
15- 23-0	20.0	18.0	2.0	7.78	5.78	25.7
19- 23-0	18.4	18.0	0.4	12.96	12.56	3.1
20- 23-0	20.8	18.0	2.8	15.90	13.10	17.6
21- 23-0	23.0	18.0	5.0	18.65	13.65	26.8
15- 24-0	21.3	18.0	3.3	6.89	3.59	47.9
20- 24-0	19.1	18.0	1.1	14.00	12.90	7.9
21- 24-0	23.3	18.0	5.3	18.80	13.50	28.2
22- 24-0	22.9	18.0	4.9	18.81	13.91	26.0
20- 25-0	18.6	18.0	0.6	13.15	12.55	4.6
21- 25-0	21.8	18.0	3.8	17.21	13.41	22.0
22- 25-0	23.8	18.0	5.8	19.70	13.90	29.4
20- 26-0	18.4	18.0	0.4	12.65	12.25	3.2
21- 26-0	20.7	18.0	2.7	16.02	13.32	16.9
22- 26-0	24.7	18.0	6.7	20.61	13.91	32.5
23- 26-0	18.0	18.0	0.0	14.23	14.23	0.0
21- 27-0	20.1	18.0	2.1	15.26	13.16	13.8
22- 27-0	23.6	18.0	5.6	19.49	13.89	28.7
23- 27-0	18.9	18.0	0.9	15.07	14.17	6.0
21- 28-0	19.2	18.0	1.2	14.54	13.34	8.3
22- 28-0	20.4	18.0	2.4	16.35	13.95	14.7

Table 4-10 NO_x Emission Volume due to Car Running in Samut Prakarn Province

<table>
<tr><th colspan="2">Year</th><th>NOx emission volume (ton/year)</th><th>Remarks</th></tr>
<tr><td colspan="2">1988</td><td>7,812</td><td>——</td></tr>
<tr><td colspan="2">1992</td><td>10,448</td><td>——</td></tr>
<tr><td rowspan="2">1999</td><td>Before taking countermeasures</td><td>15,119</td><td>——</td></tr>
<tr><td>After taking countermeasures</td><td>7,673</td><td>Japanese 1978 restricted cars to be adopted</td></tr>
</table>

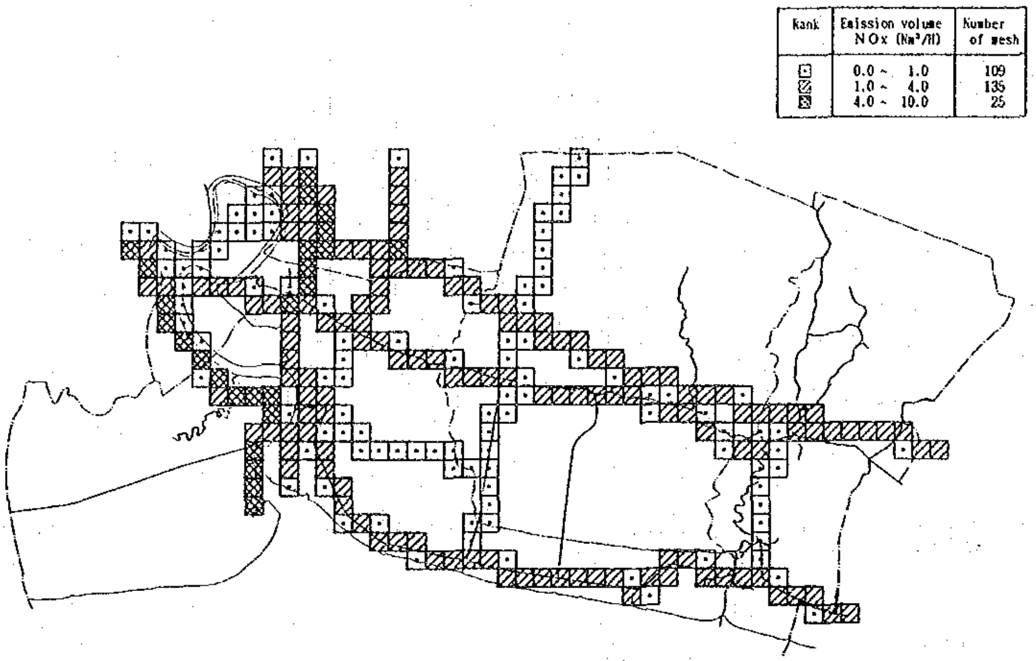


Fig. 4-2 (1) NO_x Emission Volume from Automobiles by Mesh (after taking countermeasures in 1999)

4.3 SO_2 and NO_x Emission Volumes after Implementation of Countermeasures for Emission Sources

Table 4-11 and Fig. 4-3 show the volumes of SO_2 and NO_x emitted from all areas of Samut Prakarn Province after implementation of countermeasures for emission sources. Since the countermeasure for emission sources relating to SO_2 is the K-value control method which is making stacks higher, SO_2 emission volume is the same as that (33,855 tons/year) when no source countermeasure is taken. On the other hand, NO_x emission volume reaches 24,839 tons/year due to adoption of NO_x controlled cars, accounting for a reduction of 7,446 tons/year compared with NO_x emission volume 32,285 tons/year when no countermeasure for emission sources is taken.

Table 4-11 Emission Volumes of SO_2 and NO_x from Sources in Samut Prakarn Province (upon implementation of source countermeasures)

SO_2

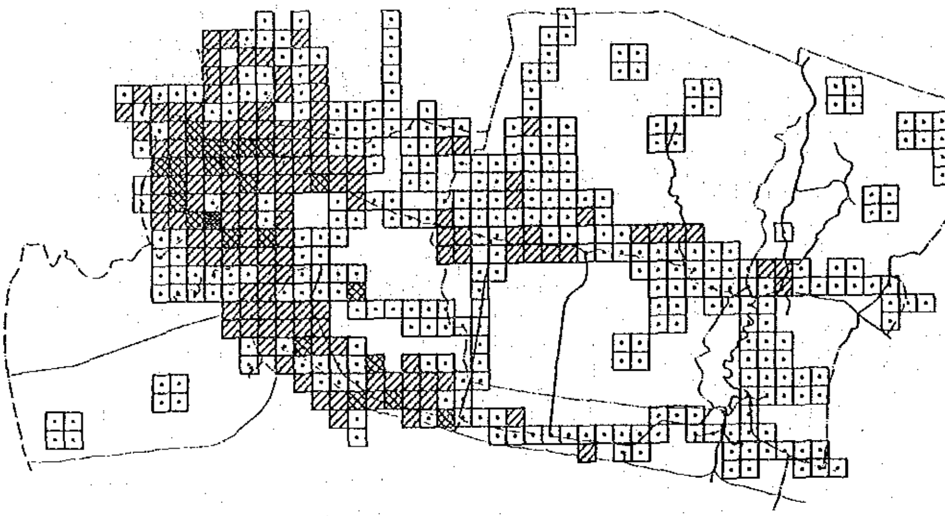
Name of source		Type of source	SO₂ emission volume (ton/year)			
			1988	1992 (92/88)	1999 (99/88) before count.	1999 (99/88) after count.
Stationary sources	Questionnaire return	point	13649	16269 (1.19)	21701 (1.59)	same as left
	Questionnaire nothing	area	4681	5580 (1.19)	7443 (1.59)	
	Industrial estate	area	—	298 (—)	298 (—)	
	Sub total		18330	22147 (1.21)	29442 (1.61)	
Road way		line	1474	1829 (1.24)	2261 (1.53)	
Vessels and Ferryboats	Vessels (sailing)	point	1263	1505 (1.19)	2007 (1.59)	
	Ferryboats (anchoring)	point	8	11 (1.38)	17 (2.16)	
	Ferryboats (sailing)	point	59	82 (1.38)	128 (2.16)	
	Sub total		1330	1598 (1.20)	2152 (1.62)	
TOTAL			21134	25574 (1.21)	33855 (1.60)	

NO_x

Name of source		Type of source	NOx emission volume (ton/year)			
			1988	1992 (92/88)	1999 (99/88) before count.	1999 (99/88) after count.
Stationary sources	Questionnaire return	point	8108	9665 (1.19)	12892 (1.59)	12892 (1.59)
	Questionnaire nothing	area	712	848 (1.19)	1132 (1.59)	1132 (1.59)
	Industrial estate	area	—	28 (—)	28 (—)	28 (—)
	Sub total		8820	10541 (1.20)	14052 (1.59)	14052 (1.59)
Road way		line	7812	10448 (1.34)	15119 (1.94)	7673 (0.98)
Vessels and Ferryboats	Vessels (sailing)	point	1623	1935 (1.19)	2581 (1.59)	2581 (1.59)
	Ferryboats (anchoring)	point	26	36 (1.38)	57 (2.16)	57 (2.16)
	Ferryboats (sailing)	point	221	304 (1.38)	476 (2.16)	476 (2.16)
	Sub total		1870	2275 (1.22)	3114 (1.67)	3114 (1.67)
TOTAL			18502	23264 (1.26)	32285 (1.74)	24839 (1.34)

SO_2

Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	324
	1.0 ~ 10.0	133
	10.0 ~ 100.0	23
	100.0 ~	1



NO_x

Rank	Emission volume NO_x (Nm^3/H)	Number of mesh
	0.0 ~ 1.0	252
	1.0 ~ 10.0	214
	10.0 ~ 100.0	8
	100.0 ~	1

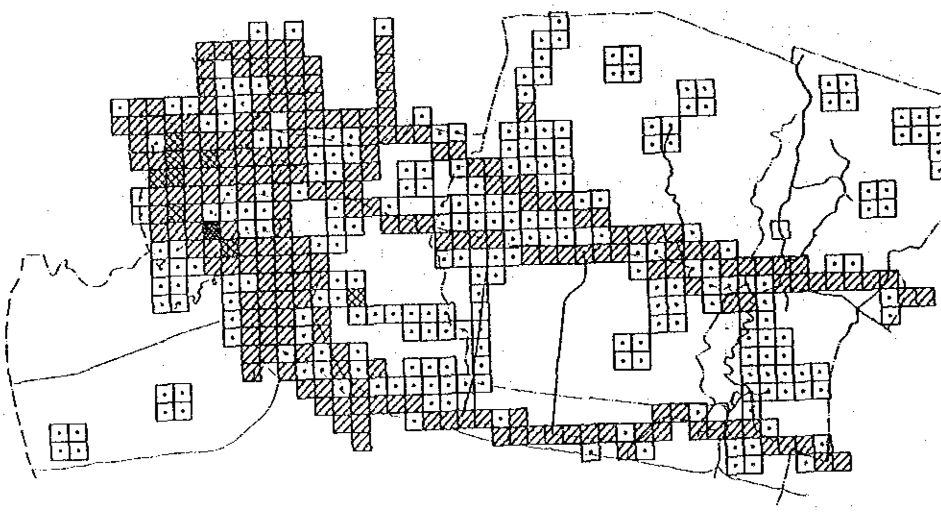


Fig. 4-3 Emission Volume of SO_2 and NO_x from All Emission Sources after Taking Countermeasures

4.4 Ambient SO_2 and NO_x Concentrations after Implementation of Countermeasures for Emission Sources

Forecast was made of SO_2 ambient concentration when K-value control would be instituted for factories in 1999. Another forecast was made of NO_2 ambient concentration when cars equivalent to 1978 NO_x emission controlled cars of Japan would be introduced in Thailand in the same year.

4.4.1 Comparisons between Ambient Pollutant Concentrations and Environmental Standard Values of All Areas

Fig. 4-4, 4-5 and Tables 4-12, 4-13 show the results of calculation of the yearly average ambient concentrations of SO_2, NO_x and NO_2 in all areas of Samut Prakarn Province. Also, Table 4-14 shows the number of meshes by concentration rank. Some areas will exceed NO_2 environmental standard in 1999 when Thailand advances the economic and social development that it has planned without taking any countermeasure for emission sources, but it can be seen that adoption of NO_x emission controlled cars will prevent any points from exceeding the environmental standards. In addition, while SO_2 concentration will in no way exceed the environmental standards in future, it is understood that implementation of K-value control for factories in 1999 will lead to further improvement of environment.

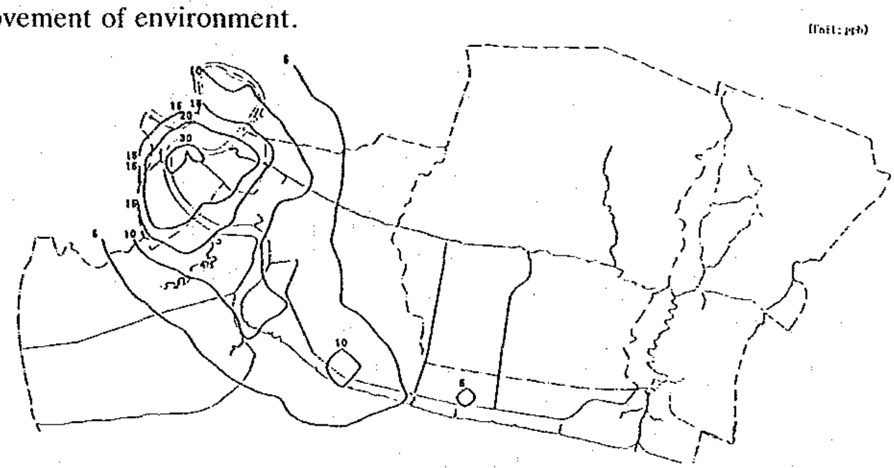


Fig. 4-4 Ambient SO_2 Concentration in Samut Prakarn Province after Implementation of K-value Control in 1999

Table 4-12 Yearly Average Concentration of SO_2 in Samut Prakarn Province after Implementation of K-value Control in 1999 (Unit: 0.1 ppb)

[illegible]

Table 4-13 Ambient Concentration of Nitrogen Oxides after Adoption of NO_x Emission Controlled Cars in 1999
(Unit ; 0.1 ppb)

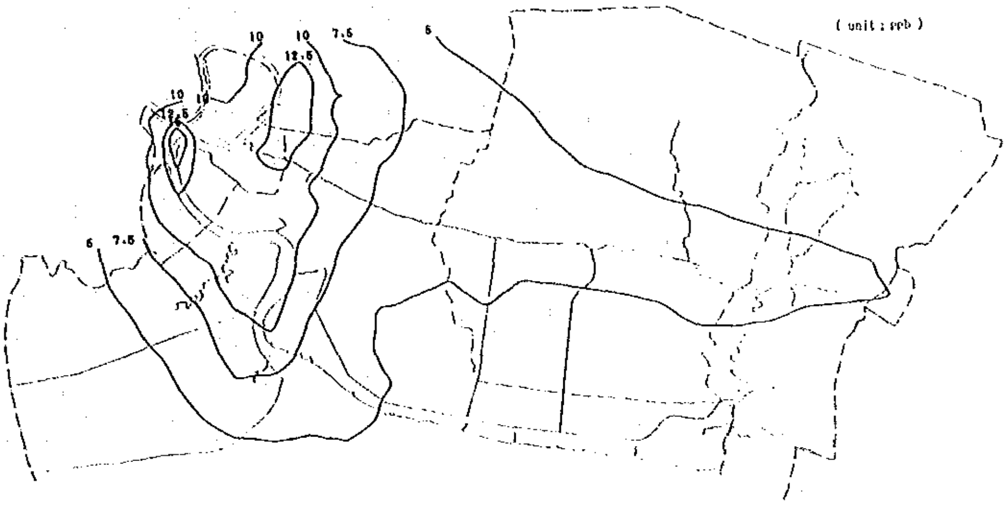
	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)	15)	16)	17)	18)	19)	20)	21)	22)	23)	24)	25)	26)	27)	28)	29)	30)	31)	32)	33)
30)																													
29)													79	82	91	101	109	104	94	76	73	71	64	57	53	49	47	44	42
28)													85	86	97	114	120	123	103	82	81	80	71	67	57	52	49	47	44
27)													94	92	100	117	125	140	114	91	90	88	78	67	61	56	53	51	48
26)									89	94	98	104	101	99	106	122	128	145	110	100	99	97	85	72	66	59	57	54	51
25)									94	105	121	117	107	107	115	121	133	141	107	96	97	93	83	77	69	65	63	60	56
24)									93	102	179	125	119	120	120	122	140	136	108	100	96	93	82	71	71	72	69	66	61
23)									94	111	141	125	124	119	120	130	138	111	104	95	91	85	77	69	69	69	69	70	65
22)									92	111	143	119	112	108	106	123	124	107	100	94	85	76	71	66	66	66	69	73	70
21)									91	115	126	117	111	105	107	117	107	103	92	92	82	74	70	65	64	63	66	69	68
20)									82	109	113	114	109	104	106	109	115	109	96	86	79	73	69	64	62	59	63	66	66
19)									77	94	110	105	103	105	107	118	118	104	91	80	75	69	65	62	59	57	60	43	62
18)		35	37	39	43	44	53	40	73	65	95	105	106	107	116	124	110	95	85	76	71	66	62	59	57	55	58	61	59
17)		34	37	39	42	46	52	58	67	77	86	95	102	110	115	121	106	92	82	72	67	62	59	54	54	53	55	57	56
16)	33	34	36	39	42	45	50	55	62	68	77	85	99	112	115	117	103	89	78	68	63	58	55	53	52	51	53	54	53
15)	32	33	35	37	40	43	47	52	58	63	71	78	91	104	108	112	97	83	73	64	59	56	52	50	50	49	50	52	50
14)	32	33	34	34	39	42	45	48	53	58	65	71	83	96	102	107	92	77	68	60	55	49	49	48	48	47	48	50	48
13)	32	33	34	35	36	40	43	46	51	55	60	66	78	91	95	99	85	72	65	56	54	49	48	46	46	45	46	47	46
12)	32	33	35	34	37	39	42	44	48	51	56	61	73	86	88	90	79	68	62	57	53	48	46	44	44	43	44	45	44
11)	32	32	33	34	35	37	40	42	46	49	54	58	68	78	78	76	72	66	61	57	53	50	48	45	44	43	44	44	44
10)	32	32	33	33	34	35	38	41	44	47	51	55	63	70	68	66	65	63	60	58	54	51	49	47	45	45	43	43	43
9)		32	33	33	34	35	37	39	41	44	48	52	57	62	61	60	59	58	57	57	53	50	48	46	44	43	44	45	45
8)		32	32	33	34	34	36	37	39	41	43	48	53	54	54	53	54	53	54	56	52	48	47	45	44	43	45	47	48
7)		32	32	33	33	34	35	36	38	39	42	44	44	48	49	50	49	49	50	50	48	45	44	42	42	41	43	45	45
6)		32	32	32	33	33	34	35	36	37	39	41	42	43	44	45	45	45	45	45	43	41	41	40	39	39	41	42	43
5)																													
4)																													

	34)	35)	36)	37)	38)	39)	40)	41)	42)	43)	44)	45)	46)	47)	48)	49)	50)	51)	52)	53)	54)	55)	56)	57)	58)	59)	60)	61)
30)	38	37	36	34	32	31	29	29	29	29	29																	
29)	40	39	38	36	34	32	31	31	30	30	29	29	29	29														
28)	42	40	39	37	35	34	33	32	31	30	29	29	29	29	29	29	29	28	28									
27)	45	43	41	39	37	36	36	34	33	32	31	30	30	30	29	29	29	28	28	28	28							
26)	48	45	43	41	39	37	36	35	34	33	32	32	32	31	30	29	29	28	28	28	28	28	28	28				
25)	52	48	45	43	41	39	38	37	36	35	34	34	34	33	32	32	31	31	30	30	30	30	30	29	29	29	28	
24)	54	51	47	45	42	41	40	39	38	37	36	36	36	35	36	34	33	33	33	37	32	31	31	30	30	29	28	
23)	61	56	51	48	45	44	42	41	40	39	38	38	37	37	34	35	35	36	34	33	33	32	32	31	30	30	29	
22)	64	60	54	51	48	46	45	43	42	41	40	39	39	38	38	37	34	36	35	34	33	33	32	32	31	30	30	27
21)	66	61	54	51	53	51	49	47	45	44	43	42	41	40	40	39	38	37	34	36	35	34	33	32	32	31	30	30
20)	65	62	59	58	56	55	53	51	49	47	46	44	43	43	42	41	40	39	37	37	36	35	34	35	32	31	30	
19)	41	60	58	59	60	58	57	55	54	55	52	50	48	47	46	44	43	42	40	39	38	37	36	34	33	32		
18)	55	58	58	60	62	61	60	59	59	58	58	55	52	51	49	48	46	44	43	41	40	38	37	35	35			
17)	55	55	53	57	58	56	56	56	59	60	60	58	57	56	55	54	52	50	48	46	44	42	40	38				
16)	52	52	52	53	54	55	56	57	59	61	63	62	61	61	61	59	58	55	53	51	49	46	44					
15)	49	49	49	50	51	51	52	53	53	57	59	58	58	58	58	56	55	54	52	51	50	48	46					
14)	46	46	44	47	47	48	48	49	50	52	54	55	53	55	55	55	52	52	52	51	51	49	48					
13)	45	45	45	45	45	46	47	48	48	50	51	51	51	51	51	49	48	47	47	46	46	44	42					
12)	43	43	43	44	44	44	45	46	46	47	48	48	48	48	47	45	44	43	42	41	40	39						
11)	43	43	43	43	43	44	44	45	46	47	47	47	47	46	45	44	42	41	40									
10)	42	42	43	43	43	43	44	45	46	46	46	46	46	45	44	42	41	40	39									
9)	45	45	45	44	44	45	45	46	47	48	48	48	48	46	45	43	41	40	38									
8)	48	48	47	46	46	46	46	47	49	49	49	49	49	48	44	44	42	40										
7)	46	46	46	46	46	45	45	46	46	46	46	46	46	46	45	44	43	41										
6)	43	44	44	45	45	45	44	44	43	43	42	43	44	44	45	44	44	42										
5)							41	40	40	39	39	40	40	40	41	41	41	39										
4)													36	37	37	38												

	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)	15)	16)	17)	18)	19)	20)	21)	22)	23)	24)	25)	26)	27)	28)	29)	30)	31)	32)	33)
30)																													
29)													146	149	152	156	163	155	138	105	100	97	87	76	70	63	60	57	54
28)													148	138	156	194	163	183	151	114	112	110	97	83	75	67	64	61	57
27)													143	143	153	190	196	213	170	130	127	124	107	91	82	72	69	66	62
26)									161	163	164	184	175	156	166	206	198	224	147	148	143	137	118	99	88	77	74	71	67
25)									155	192	236	225	164	174	195	202	203	215	162	139	141	136	118	100	95	90	85	80	75
24)									159	166	487	253	226	222	221	195	220	209	162	142	139	135	118	102	102	102	96	90	83
23)									156	214	401	239	240	217	204	215	220	174	153	132	129	120	108	95	96	97	97	97	92
22)									132	212	324	228	216	192	186	196	196	162	150	135	120	105	97	89	90	92	98	104	100
21)									130	213	262	223	211	186	176	186	168	154	134	136	116	103	96	88	87	85	91	96	95
20)									133	203	220	224	199	175	165	167	173	137	136	122	112	101	94	88	83	79	84	89	91
19)									122	173	199	190	191	176	171	180	183	149	124	113	105	96	90	84	80	77	81	84	86
18)		47	50	53	56	64	76	88	113	139	161	182	180	178	190	203	170	137	122	106	98	91	85	80	77	75	79	82	81
17)		46	49	53	58	63	73	83	102	121	139	158	168	179	188	198	147	135	119	102	94	86	80	74	72	71	74	77	75
16)	43	45	49	52	58	63	71	79	91	103	118	134	157	180	184	192	163	133	116	99	89	80	75	69	68	66	69	71	69
15)	43	44	48	51	56	60	67	74	85	95	107	120	143	165	176	187	156	126	110	95	85	75	71	67	65	64	66	68	66
14)	43	44	47	49	54	58	64	70	78	87	97	107	129	150	166	181	150	118	104	91	80	70	67	64	63	62	63	65	62
13)	43	44	46	48	52	56	61	67	74	81	90	98	120	143	160	179	146	112	100	88	79	70	66	62	61	59	61	62	60
12)	43	44	45	46	51	55	59	63	69	75	82	90	111	132	153	177	142	106	94	86	78	71	66	61	59	57	58	59	57
11)	42	43	45	46	49	52	56	60	65	71	78	85	102	119	129	140	127	114	101	89	83	77	71	66	61	58	58	58	57
10)	42	43	44	45	47	49	53	57	62	66	73	79	92	105	104	105	113	122	107	92	88	84	76	68	63	59	58	57	56
9)		43	44	45	46	48	51	54	58	62	68	73	82	91	91	91	95	100	99	97	89	79	74	69	65	62	62	61	64
8)		42	43	44	46	47	49	51	54	57	62	67	72	76	77	78	78	78	92	106	90	74	72	69	67	65	65	66	71
7)		42	43	44	45	46	48	50	52	54	58	62	65	68	69	70	70	70	78	65	76	66	66	62	60	59	60	61	64
6)		42	42	43	44	45	46	48	50	51	54	56	58	60	61	62	62	62	64	65	61	58	56	54	54	53	54	56	57
5)																													
4)																													

	34)	35)	36)	37)	38)	39)	40)	41)	42)	43)	44)	45)	46)	47)	48)	49)	50)	51)	52)	53)	54)	55)	56)	57)	58)	59)	60)	61)
30)	49	48	47	44	41	39	37	37	37	37	37																	
29)	51	50	49	46	43	41	40	39	38	37	37	36	36	36														
28)	54	53	51	48	45	45	42	41	39	38	37	36	36	36	36	36	36	36	36									
27)	59	56	54	50	47	45	44	43	42	40	39	38	38	38	37	36	36	36	36	36	36							
26)	64	60	54	53	49	47	46	45	44	42	41	41	40	39	38	37	36	36	36	36	36	36	36	35				
25)	70	65	59	55	52	50	48	47	46	45	43	43	43	42	41	40	39	39	38	38	38	37	37	37	36	36	35	
24)	77	69	61	58	54	52	50	49	48	47	46	45	45	44	43	42	42	41	41	40	40	39	39	38	37	36	35	
23)	86	77	67	62	58	56	54	52	51	49	48	48	47	46	45	44	44	43	43	42	41	40	40	39	38	37	36	
22)	96	86	72	67	62	59	57	55	53	52	51	50	49	48	47	46	46	45	44	43	42	41	41	40	39	38	37	37
21)	94	86	77	75	72	68	64	61	59	57	55	55	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37
20)	93	88	83	82	82	76	71	67	64	61	59	57	55	54	53	52	51	49	47	46	45	44	43	42	40	39	38	
19)	86	83	81	83	85	82	78	77	76	75	71	66	62	60	58	57	55	53	51	49	48	46	45	43	41	40		
18)	79	79	80	84	86	87	85	87	86	85	83	76	69	66	64	62	59	57	54	52	50	48	46	44	42			
17)	73	74	74	77	80	80	80	82	84	85	86	81	77	76	75	72	70	67	64	61	58	55	52	48				
16)	68	68	69	70	71	73	75	78	81	85	89	87	84	85	86	85	81	77	73	70	66	61	57					
15)	63	64	64	65	66	67	68	71	73	77	80	79	78	79	79	77	75	73	72	70	68	64	61					
14)	59	59	59	59	60	61	62	63	65	66	72	72	72	72	72	70	69	69	70	70	70	68	65					
13)	57	57	57	57	58	59	59	61	62	64	66	67	67	66	66	64	62	62	61	61	60	58	56					
12)	56	55	55	56	56	56	57	58	59	60	61	61	62	61	59	57	55	54	53	52	51	49						
11)	55	55	55	55	55	56	56	57	59	59	60	60	60	59	58	55	53	52	51									
10)	55	55	55	54	54	55	56	57	58	59	59	59	58	57	56	54	51	50	49									
9)	66	63	59	59	58	58	58	60	62	63	63	63	63	61	58	55	52	50	48									
8)	77	71	64	63	61	61	60	63	66	67	67	67	67	64	61	57	53	50										
7)	67	65	65	63	63	62	60	61	61	65	61	62	63	62	61	59	57	53										
6)	58	59	61	63	64	62	60	59	57	56	55	57	58	60	61	61	60	57										
5)							56	53	51	51	50	51	52	53	54	55	55	51										
4)													46	47	47	49												

NO$_2$



NO$_x$

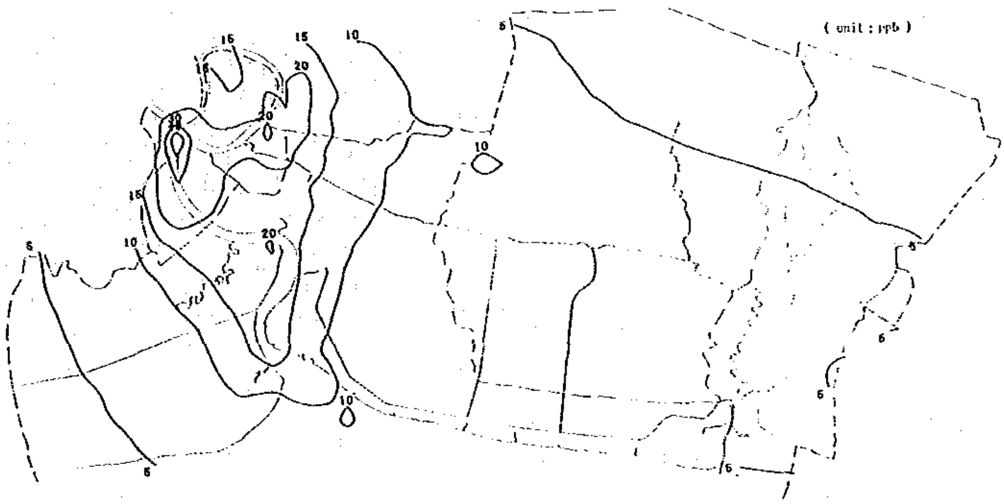


Fig. 4-5 Ambient Concentration of Nitrogen Oxides after Adoption of NO$_x$ Emission Controlled Cars in 1999

Table 4-14 Number of Meshes by Ranking of Concentrations of Air Pollutants (When countermeasres are implemented)

(SO$_2$)

Rank of cocentration (ppb)	Number of mesh		
	1988	1992	1999
0.0~ 5.0	977	929	885
5.0~10.0	128	154	150
10.0~15.0	28	42	67
15.0~20.0	21	16	24
20.0~25.0	5	14	13
25.0~30.0	0	4	13
30.0~35.0	0	0	6
35.0~40.0	0	0	1
TOTAL	1159	1159	1159

(NO$_2$)

Rank of cocentration (ppb)	Number of mesh		
	1988	1992	1999
0.0~ 5.0	674	476	300
5.0~ 7.5	305	429	437
7.5~10.0	109	104	190
10.0~12.5	64	93	68
12.5~15.0	7	46	55
15.0~17.5	0	10	68
17.5~20.0	0	1	28
20.0~22.5	0	0	7
22.5~25.0	0	0	6
TOTAL	1159	1159	1159

(NOx)

Rank of cocentration (ppb)	Number of mesh		
	1988	1992	1999
0.0~ 5.0	277	223	169
5.0~10.0	676	643	544
10.0~15.0	116	141	228
15.0~20.0	79	92	68
20.0~25.0	9	51	68
25.0~30.0	2	7	61
30.0~35.0	0	1	13
35.0~40.0	0	1	6
40.0~45.0	0	0	0
45.0~50.0	0	0	1
50.0~55.0	0	0	1
TOTAL	1159	1159	1159

4.4.2 Contribution Rate and Contributory Concentration by Emission Source

Table 4-15 and 4-16 show the contributory concentrations and contribution rates by emission source for the top 8 points of the highest concentration of SO_2 and NO_2 (all below environmental control standard value) after implementation of countermeasures. As compared with contributory concentrations by emission source (Table 3-5) when no countermeaure is taken, the contributory concentration of SO_2 of sources at factory point source is lower due to K-value control for factories. Looking at NO_2 contributory concentration, it can be seen that adoption of NO_x emission controlled cars induces a reduction in the contributory concentration of cars and that the contributory concentration of factory points source is also reduced as factory stacks are made higher.

Table 4-15 Contributory Concentrations by Emission Sources at SO_2 High Concentration Points after Implementation of K-value Control

(Rank 1 IX,IY=15,23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	47	3	1.278	4.0
	2)	3	47	1	1.140	3.6
	3)	3	47	2	1.140	3.6
	4)	3	75	1	0.768	2.4
	5)	3	5	2	0.611	1.9
	6)	3	5	1	0.521	1.6
	7)	3	4	1	0.485	1.5
	8)	3	50	2	0.459	1.4
	9)	3	54	1	0.425	1.3
	10)	3	111	2	0.425	1.3
	Remaining stacks				8.373	26.3
	Sub total				15.625	49.1
Factory (area source)					7.719	24.3
Factory(industrial estate)					0.006	0.0
Roadways					1.199	3.8
Vessels (sailing)					3.593	11.3
Ferryboats (anchoring)					0.436	1.4
Ferryboats (sailing)					3.151	9.9
Back ground					0.100	0.3
TOTAL					31.830	100.0

(Rank 2 IX,IY=17,23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	111	2	1.779	5.9
	2)	3	111	3	1.336	4.6
	3)	3	14	1	1.002	3.3
	4)	3	14	2	1.002	3.3
	5)	3	4	2	0.988	3.3
	6)	3	69	1	0.821	2.7
	7)	3	14	3	0.819	2.7
	8)	3	111	4	0.788	2.6
	9)	3	98	5	0.633	2.1
	10)	3	4	1	0.374	1.2
	Remaining stacks				6.891	22.7
	Sub total				16.439	54.4
Factory (area source)					9.544	31.5
Factory(industrial estate)					0.012	0.0
Roadways					1.610	5.3
Vessels (sailing)					2.480	8.2
Ferryboats (anchoring)					0.007	0.0
Ferryboats (sailing)					0.063	0.2
Back ground					0.100	0.3
TOTAL					30.295	100.0

(Rank 3 IX,IY=16,24)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	75	1	1.391	4.6
	2)	3	4	1	1.155	3.8
	3)	3	111	2	0.850	2.8
	4)	3	69	1	0.686	2.3
	5)	3	52	2	0.582	1.9
	6)	3	14	1	0.555	1.8
	7)	3	14	2	0.555	1.8
	8)	3	118	2	0.510	1.7
	9)	3	98	5	0.501	1.7
	10)	3	47	3	0.496	1.6
	Remaining stacks				7.681	25.5
	Sub total				14.948	49.6
Factory (area source)					9.563	31.7
Factory(industrial estate)					0.006	0.0
Roadways					1.410	4.7
Vessels (sailing)					3.721	12.3
Ferryboats (anchoring)					0.066	0.2
Ferryboats (sailing)					0.333	1.1
Back ground					0.100	0.3
TOTAL					30.137	100.0

(Rank 4 IX,IY=16,23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	4	1	1.176	3.9
	2)	3	47	3	0.814	2.7
	3)	3	52	2	0.797	2.7
	4)	3	69	1	0.774	2.6
	5)	3	47	1	0.730	2.4
	6)	3	47	2	0.730	2.4
	7)	3	111	2	0.686	2.3
	8)	3	14	1	0.635	2.1
	9)	3	14	2	0.635	2.1
	10)	3	98	5	0.543	1.8
	Remaining stacks				7.989	26.8
	Sub total				15.489	51.9
Factory (area source)					10.095	33.9
Factory(industrial estate)					0.009	0.0
Roadways					1.494	5.0
Vessels (sailing)					2.351	7.9
Ferryboats (anchoring)					0.037	0.1
Ferryboats (sailing)					0.239	0.8
Back ground					0.100	0.3
TOTAL					29.816	100.0

(Rank 5 IX,IY=15,22)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	47	3	0.860	2.9
	2)	3	51	2	0.733	2.5
	3)	3	47	1	0.723	2.4
	4)	3	47	2	0.723	2.4
	5)	3	51	3	0.656	2.2
	6)	3	75	1	0.561	1.9
	7)	3	54	1	0.531	1.8
	8)	3	111	2	0.520	1.8
	9)	3	4	1	0.485	1.6
	10)	3	51	1	0.437	1.5
	Remaining stacks				7.884	26.7
	Sub total				14.100	47.7
Factory (area source)					8.633	29.2
Factory(industrial estate)					0.003	0.0
Roadways					1.383	4.7
Vessels (sailing)					3.519	11.9
Ferryboats (anchoring)					0.117	0.4
Ferryboats (sailing)					1.729	5.8
Back ground					0.100	0.3
TOTAL					29.586	100.0

(Rank 6 IX,IY=17,24)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	14	2	1.300	4.4
	2)	3	14	1	1.300	4.4
	3)	3	111	2	1.164	4.0
	4)	3	4	1	1.156	3.9
	5)	3	14	3	0.884	3.0
	6)	3	4	2	0.731	2.5
	7)	3	69	1	0.656	2.2
	8)	3	98	5	0.552	1.9
	9)	3	13	2	0.530	1.8
	10)	3	13	1	0.520	1.8
	Remaining stacks				7.151	24.4
	Sub total				15.917	54.3
Factory (area source)					8.878	30.3
Factory(industrial estate)					0.003	0.0
Roadways					1.440	4.9
Vessels (sailing)					2.870	9.8
Ferryboats (anchoring)					0.011	0.0
Ferryboats (sailing)					0.079	0.3
Back ground					0.100	0.3
TOTAL					29.304	100.0

(Rank 7 IX,IY=15,21)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	47	3	1.239	4.3
	2)	3	47	2	1.063	3.7
	3)	3	47	1	1.063	3.7
	4)	3	111	2	0.452	1.6
	5)	3	96	2	0.421	1.4
	6)	3	14	2	0.358	1.2
	7)	3	14	1	0.358	1.2
	8)	3	5	2	0.333	1.1
	9)	3	79	1	0.314	1.1
	10)	3	75	1	0.304	1.0
	Remaining stacks				7.843	27.0
	Sub total				13.746	47.2
Factory (area source)					9.788	33.6
Factory(industrial estate)					0.010	0.0
Roadways					1.398	4.8
Vessels (sailing)					3.566	12.2
Ferryboats (anchoring)					0.045	0.2
Ferryboats (sailing)					0.450	1.5
Back ground					0.100	0.3
TOTAL					29.093	100.0

(Rank 8 IX,IY=15,24)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	5	2	0.813	2.9
	2)	3	5	1	0.682	2.4
	3)	3	75	1	0.618	2.2
	4)	3	47	3	0.560	2.0
	5)	3	47	1	0.536	1.9
	6)	3	47	2	0.536	1.9
	7)	3	98	5	0.415	1.5
	8)	3	111	2	0.400	1.4
	9)	3	4	1	0.330	1.3
	10)	3	52	2	0.300	1.3
	Remaining stacks				6.351	22.6
	Sub total				11.641	41.4
Factory (area source)					6.051	21.5
Factory(industrial estate)					0.003	0.0
Roadways					1.033	3.7
Vessels (sailing)					3.732	13.3
Ferryboats (anchoring)					0.976	3.5
Ferryboats (sailing)					4.601	16.3
Back ground					0.100	0.4
TOTAL					28.143	100.0

Table 4-16 Contributory Concentration by Emission Sources at NO_2 High Concentration Points after Adoption of NO_x Emission Controlled Cars in 1999

(Rank 1 IX, IY=15, 24)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.125	0.7
	2)	3	98	3	0.077	0.4
	3)	3	98	4	0.067	0.4
	4)	3	98	1	0.053	0.3
	5)	3	98	2	0.052	0.3
	6)	3	105	2	0.037	0.2
	7)	3	105	3	0.037	0.2
	8)	3	105	1	0.025	0.1
	9)	3	5	2	0.021	0.1
	10)	3	5	1	0.017	0.1
	Remaining stacks				0.274	1.5
	Sub total				0.785	4.4
Factory (area source)					0.800	4.5
Factory (industrial estate)					0.000	0.0
Roadways					3.493	19.6
Vessels (sailing)					2.418	13.5
Ferryboats (anchoring)					1.150	6.4
Ferryboats (sailing)					6.415	35.9
Back ground					2.800	15.7
TOTAL					17.866	100.0

(Rank 2 IX, IY=15, 23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.117	0.7
	2)	3	98	3	0.074	0.5
	3)	3	98	4	0.063	0.4
	4)	3	98	1	0.053	0.3
	5)	3	98	2	0.053	0.3
	6)	3	105	2	0.040	0.2
	7)	3	105	3	0.040	0.2
	8)	3	105	1	0.028	0.2
	9)	3	47	3	0.021	0.1
	10)	3	47	1	0.019	0.1
	Remaining stacks				0.331	2.1
	Sub total				0.839	5.2
Factory (area source)					1.020	6.3
Factory (industrial estate)					0.001	0.0
Roadways					3.949	24.5
Vessels (sailing)					2.343	14.5
Ferryboats (anchoring)					0.554	3.4
Ferryboats (sailing)					4.603	28.6
Back ground					2.800	17.4
TOTAL					16.109	100.0

(Rank 3 IX, IY=22, 26)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.078	0.5
	2)	3	98	3	0.047	0.3
	3)	3	98	4	0.042	0.3
	4)	3	98	1	0.030	0.2
	5)	3	98	2	0.030	0.2
	6)	3	105	2	0.023	0.2
	7)	3	105	3	0.023	0.2
	8)	3	105	1	0.015	0.1
	9)	1	70	2	0.008	0.1
	10)	1	39	1	0.008	0.1
	Remaining stacks				0.111	0.8
	Sub total				0.415	2.9
Factory (area source)					0.247	1.7
Factory (industrial estate)					0.002	0.0
Roadways					10.460	71.9
Vessels (sailing)					0.592	4.1
Ferryboats (anchoring)					0.004	0.0
Ferryboats (sailing)					0.029	0.2
Back ground					2.800	19.2
TOTAL					14.549	100.0

(Rank 4 IX, IY=15, 22)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.098	0.7
	2)	3	98	3	0.063	0.4
	3)	3	98	4	0.053	0.4
	4)	3	98	1	0.048	0.3
	5)	3	98	2	0.047	0.3
	6)	3	105	2	0.042	0.3
	7)	3	105	3	0.042	0.3
	8)	3	105	1	0.032	0.2
	9)	3	51	1	0.028	0.2
	10)	3	51	2	0.018	0.1
	Remaining stacks				0.295	2.1
	Sub total				0.766	5.3
Factory (area source)					1.212	8.5
Factory (industrial estate)					0.001	0.0
Roadways					4.498	31.4
Vessels (sailing)					2.215	15.4
Ferryboats (anchoring)					0.199	1.4
Ferryboats (sailing)					2.647	18.5
Back ground					2.800	19.5
TOTAL					14.338	100.0

(Rank 5 IX, IY=22, 25)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.073	0.5
	2)	3	98	3	0.044	0.3
	3)	3	98	4	0.039	0.3
	4)	3	98	2	0.030	0.2
	5)	3	98	1	0.029	0.2
	6)	3	105	2	0.024	0.2
	7)	3	105	3	0.024	0.2
	8)	3	105	1	0.016	0.1
	9)	1	39	1	0.011	0.1
	10)	1	70	2	0.009	0.1
	Remaining stacks				0.125	0.9
	Sub total				0.424	3.0
Factory (area source)					0.289	2.1
Factory (industrial estate)					0.002	0.0
Roadways					9.999	71.0
Vessels (sailing)					0.547	3.9
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.024	0.2
Back ground					2.800	19.9
TOTAL					14.088	100.0

(Rank 6 IX, IY=21, 24)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.081	0.6
	2)	3	98	3	0.049	0.3
	3)	3	98	4	0.043	0.3
	4)	3	98	1	0.035	0.2
	5)	3	98	2	0.035	0.2
	6)	3	105	2	0.031	0.2
	7)	3	105	3	0.031	0.2
	8)	3	105	1	0.021	0.1
	9)	1	39	1	0.010	0.1
	10)	1	70	2	0.009	0.1
	Remaining stacks				0.173	1.2
	Sub total				0.518	3.7
Factory (area source)					0.441	3.1
Factory (industrial estate)					0.002	0.0
Roadways					9.539	68.0
Vessels (sailing)					0.698	5.0
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.026	0.2
Back ground					2.800	20.0
TOTAL					14.027	100.0

(Rank 7 IX, IY=22, 27)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.080	0.6
	2)	3	98	3	0.048	0.3
	3)	3	98	4	0.043	0.3
	4)	3	98	1	0.030	0.2
	5)	3	98	2	0.030	0.2
	6)	3	105	2	0.022	0.2
	7)	3	105	3	0.022	0.2
	8)	3	105	1	0.014	0.1
	9)	1	70	2	0.007	0.1
	10)	1	70	1	0.006	0.0
	Remaining stacks				0.098	0.7
	Sub total				0.400	2.9
Factory (area source)					0.211	1.5
Factory (industrial estate)					0.001	0.0
Roadways					9.891	70.8
Vessels (sailing)					0.630	4.5
Ferryboats (anchoring)					0.004	0.0
Ferryboats (sailing)					0.034	0.2
Back ground					2.800	20.0
TOTAL					13.971	100.0

(Rank 8 IX, IY=21, 23)

Type of source	SEQ)	County	Fact No.	Sta. No.	Conce. of contr. (ppb)	Rate of contr. (%)
Factory (point)	1)	3	98	5	0.066	0.5
	2)	3	98	3	0.041	0.3
	3)	3	98	4	0.035	0.3
	4)	3	105	2	0.032	0.2
	5)	3	105	3	0.032	0.2
	6)	3	98	2	0.031	0.2
	7)	3	98	1	0.030	0.2
	8)	3	105	1	0.022	0.2
	9)	1	70	2	0.010	0.1
	10)	1	39	1	0.010	0.1
	Remaining stacks				0.182	1.3
	Sub total				0.491	3.6
Factory (area source)					0.412	3.0
Factory (industrial estate)					0.002	0.0
Roadways					9.465	68.5
Vessels (sailing)					0.631	4.6
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.021	0.2
Back ground					2.800	20.3
TOTAL					13.825	100.0

PART VII SPECIFIC REMEDIES FOR EMISSION SOURCES, COST ESTIMATION, AND ANALYSIS OF ECONOMIC IMPACTS

1. Outline

In view of the considerations in the preceding Part VI, if emission controls for factories are to be adopted in the future, then we feel that the K-value controls are appropriate and we came to the conclusion that the most practical method would be to increase the height of stacks. Moreover, it was found that the appropriate value of K is 13 and that the stacks, for which countermeasures are really required, are 49 units in number. Thus, this Part VII will hereafter discuss the roughly estimated expenses required to implement the countermeasures, and the impact of such investment on the economy of the Samut Prakarn regions or Thailand as a whole. Also described are overview of remedial other options for controlling SO_2 emission than making stacks taller besides the general picture of reduction techniques for NO_x and particulate matters are also described.

2. Practice of Making Stacks Taller and Their Investment Cost

2.1 Determinants of the Stack Structure

If K=13, the number of stacks to be made taller is 49 as attested by Table 4-4 of Part VI. Though these facilities are called stacks, there are some which are simply emission outlets or which, if actual stacks, do not sufficiently contribute to the diffusion of pollutants because of an umbrella placed on top. As a consequence, it is not necessarily realistic to make stacks taller. Generally, the factors for determination of a stack structure include the items specified below, which should be fully examined in light of laws and regulations or the functions of a stack.

2.1.1 Meteorological and Site Conditions

It is necessary to grasp the current and future conditions of the site surrounding stacks and examine such meteorological conditions as wind direction and wind velocity, as well as geographical features. it is further necessary to study the stack heights (over 2.5 times those of adjacent buildings) and the discharge velocity at stack mouths (over twice the wind velocity) in order to avoid adverse effects on adjacent buildings, such as downwash or downdraft.

2.1.2 Pressure Loss and Effective Draft

After considering the combustion conditions of a boiler, the capacity of a blower and pressure loss of a path to a stack, the effective draft of combustion (effective draft power) is set to determine the structure of a stack.

The effective draft power of a stack is calculated as follows:

$$H_t = H_o - P_{total} \quad \cdots\cdots \quad (2\text{-}1)$$

$$H_o = h(\rho_a - \rho_g) \quad \cdots\cdots \quad (2\text{-}2)$$

$$P_{total} = P_t+P_b+P_f \quad \text{(2-3)}$$

$$P_t = \zeta_1 \times \frac{\varrho g \times V^2}{2\times G} \quad \text{(2-4)}$$

$$P_b = \zeta_2 \times \frac{\varrho g \times V^2}{2\times G} \quad \text{(2-5)}$$

$$P_f = \lambda \times \frac{h}{D} \times \frac{\varrho g \times V^2}{2\times G} \quad \text{(2-6)}$$

where;

H_t : Effective draft of a stack (m)

H_o : Theoretical draft of a stack (m)

h : Stack height (m)

ϱ_a : Specific weight of air (kg/m^3)

ϱ_g : Specific weight of emission gas (kg/m^3)

P_{total}: Total pressure loss

P_t : Extrusion loss

P_b : Curve loss

P_f : Friction loss

ζ_1, ζ_2, λ: Loss factor

V : Flow rate of emission gas (m/s)

G : Acceleration of gravity (m/s^2)

D : Internal diameter of stack (m)

2.1.3 Establishment of Actual Stack Height

With effective stack height calculated, the actual stack height is established. Effective stack height can be calculated based on an emission standard (K value). That is to say, in Samut Prakarn province, the adoption of K=13 leads to the calculation of the effective stack height (He) based on the following equation (2-7):

$$He = (q\times 10^3/K)^{1/2}$$
$$= 8.771\sqrt{q} \quad \text{(2-7)}$$

where;

q: Emission volume of SO_2 (Nm^3/h)

2.2 Prerequisites for Study of Making Stacks Taller

2.2.1 Stack Structures

Roughly divided, there are the following 4 types of structures in building stacks. (See Fig. 2-1.)

① Self standing

This is suitable for small-size stacks. However, it is necessary to take into consideration vibration caused by Kàrman vortex, and this type is unfavorable when the radius of a stack is small. In addition, thermal insulation is required according to emission gas conditions.

② Supported by RC shell

This is suitable for medium- and large-size stacks. Adiabatic insulation is required if the temperature of emission gas is high.

③ Supported by steel shell

This is suitable for medium- and large-size stacks. Although no thermal insulation is necessary regardless of the emission gas conditions, coating of the outer shell is required (once every 5 to 10 years).

④ Supported by steel structure

This is suitable for medium- and large-size stacks. Thermal insulation is required according to emission gas conditions, coupled with coating of the steel structure (once every 5 to 10 years).

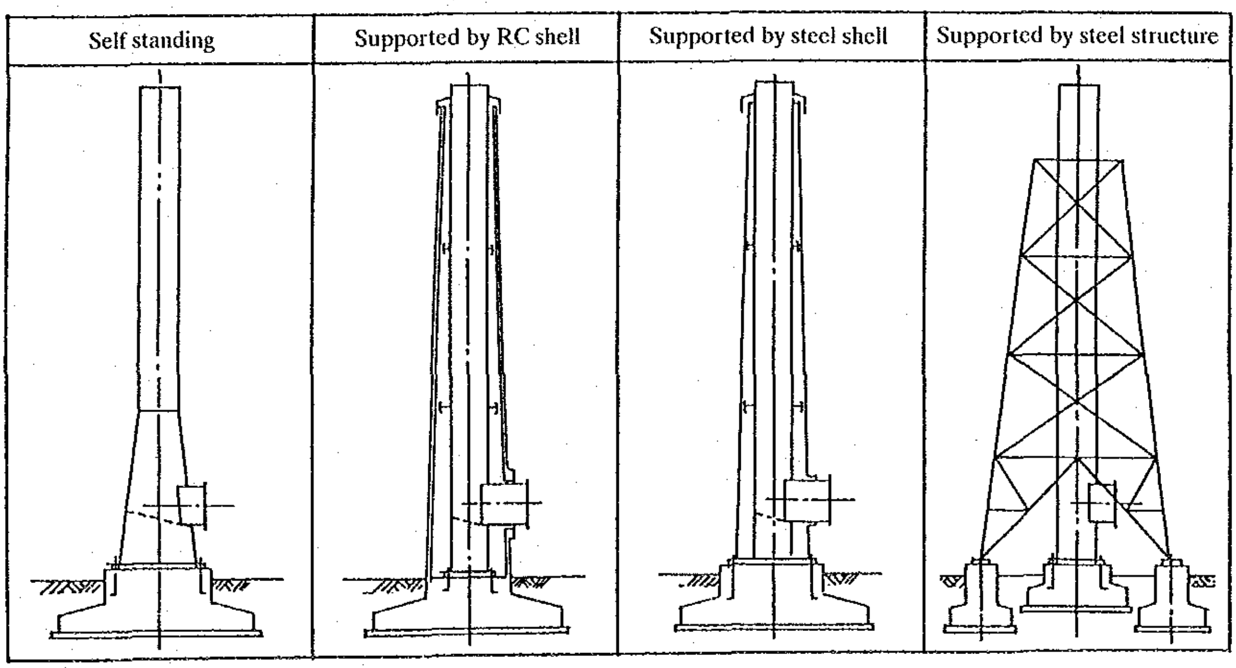


Fig. 2-1 Structures of Stacks

Since the stacks targeted in this study, as shown in Table 2-1, are in the range of 3 m to 38 m in stack height after the stacks are made taller, their structures should be decided after taking the conditions of individual cases into account. The individual conditions, however, are unknown for the present. We, therefore, decided to apply the "supported by steel shell" type to the most stacks, but the "self standing" type to the stacks listed in "2-24-2 (County code—Factory number—Stack number)" because its height is only 3 m after it is made taller.

Table 2-1 Stack Height Required to Fulfill K=13

SEQ	County code	Factory No.	Stack No.	Present stack height H_o (m)	Gas temperature T (°K)	Normal exhaust gas volume Q (m^3/S)	Normal SO_2 emission volume q (Nm^3/h)	New Stack Dia. (m) Internal Sus Tube	New Stack Dia. (m) External Cs Stack	New stack height H_u (m)
1)	3	75	1	5	313	26.092	31.697	1.55	2.2/3.5	38.0
2)	3	34	3	5	350	2.935	5.610	0.55	1.2/1.6	17.0
3)	2	23	4	5	350	2.697	3.281	0.53	1.2/1.2	12.5
4)	1	68	2	20	462	6.712	28.970	0.96	1.6/3.4	37.0
5)	3	23	5	5	333	4.349	2.633	0.65	1.3/1.3	10.0
6)	3	24	1	7	462	0.350	1.812	0.22	0.9/1.0	10.5
7)	2	24	2	2	437	0.157	0.186	0.14	—	3.0
8)	3	96	1	5	350	5.849	4.548	0.78	1.4/1.4	13.0
9)	3	33	2	6	437	0.007	0.971	0.03	0.7/0.8	8.5
10)	1	39	1	15	462	2.940	18.078	0.63	1.3/2.9	31.5
11)	2	19	2	6	523	0.519	2.019	0.28	0.9/1.0	10.5
12)	3	97	1	5	318	0.125	0.652	0.11	0.8/0.8	6.5
13)	1	68	1	15	462	1.860	8.047	0.50	1.2/1.9	21.0
14)	1	66	1	10	453	1.570	6.206	0.46	1.1/1.7	18.5
15)	3	59	2	10	443	1.852	6.647	0.49	1.1/1.7	19.0
16)	3	111	2	22	496	6.119	24.545	0.95	1.6/3.0	33.0
17)	1	56	2	6	448	1.482	2.703	0.44	1.1/1.1	11.0
18)	3	14	1	20	483	4.587	16.464	0.81	1.5/2.5	27.5
19)	3	14	2	20	483	4.587	16.464	0.81	1.5/2.5	27.5
20)	3	109	2	12	462	0.926	4.858	0.36	1.0/1.6	17.0
21)	3	90	1	10	462	0.932	3.649	0.36	1.0/1.4	14.5
22)	1	70	3	6	437	1.639	2.567	0.46	1.1/1.1	10.5
23)	1	35	2	15	483	1.305	5.895	0.43	1.1/1.7	18.0
24)	3	54	1	16	448	1.864	9.730	0.50	1.2/2.2	23.5
25)	1	35	1	15	483	1.305	5.857	0.43	1.1/1.7	18.0
26)	3	16	4	15	473	1.813	9.512	0.50	1.2/2.1	23.0
27)	3	102	1	13	462	2.319	9.008	0.56	1.2/2.0	21.5
28)	1	68	3	20	462	2.237	9.657	0.55	1.2/2.1	22.5
29)	1	66	2	14	453	2.223	8.796	0.54	1.2/2.0	21.5
30)	3	16	3	15	473	1.449	7.608	0.45	1.1/1.9	20.5
31)	3	47	3	12	498	2.025	7.922	0.55	1.2/1.9	20.0
32)	1	2	1	12	473	1.778	6.381	0.50	1.2/1.7	18.0
33)	3	109	1	15	462	1.237	6.478	0.41	1.1/1.8	19.5
34)	1	64	1	10	462	0.667	2.609	0.30	1.0/1.1	12.0
35)	1	70	2	18	573	5.406	16.113	0.96	1.6/2.2	23.5
36)	3	5	2	24	523	9.631	27.299	1.22	1.9/2.7	29.5
37)	3	16	1	15	473	1.086	5.692	0.39	1.0/1.7	18.0
38)	3	16	2	15	473	1.086	5.692	0.39	1.0/1.7	18.0
39)	1	70	1	18	573	4.317	12.890	0.85	1.5/2.0	21.5
40)	3	54	2	18	473	1.864	9.730	0.51	1.2/2.1	23.0
41)	3	54	3	18	473	1.864	9.730	0.51	1.2/2.1	23.0
42)	3	110	2	10	462	0.556	1.994	0.28	0.9/1.0	10.5
43)	2	5	6	10	462	0.608	2.226	0.29	0.9/1.1	11.5
44)	3	28	1	10	462	0.445	1.979	0.25	0.9/1.0	11.0
45)	1	55	1	30	393	4.230	22.098	0.70	1.3/3.3	35.5
46)	1	55	2	30	393	4.230	22.098	0.70	1.3/3.3	35.5
47)	3	14	3	20	483	2.293	8.232	0.57	1.2/1.9	20.0
48)	1	64	2	6	462	0.196	0.622	0.16	0.8/0.8	6.0
49)	3	95	2	7	333	1.141	0.886	0.33	1.0/1.0	7.0

2.2.2 Materials of Stacks

Since the facilities targeted for higher stacks in the present study, though naturally, emit SO_x in high concentrations, the stacks material must be stainless steel. There is commonly a correlation between the sulfuric acid dew point and the emission gas temperature as shown in Fig. 2-2. In the case that SO_x concentration is high and the gas temperature is below 200°C as in this study, it tends to fellow sulfuric acid dew point. Consequently, it is important that the stacks with a temperature lower than 200°C are designed so that the decline of emission gas temperature should be minimized by providing 50 mm of rock wool as adiabatic material between the internal and external shells.

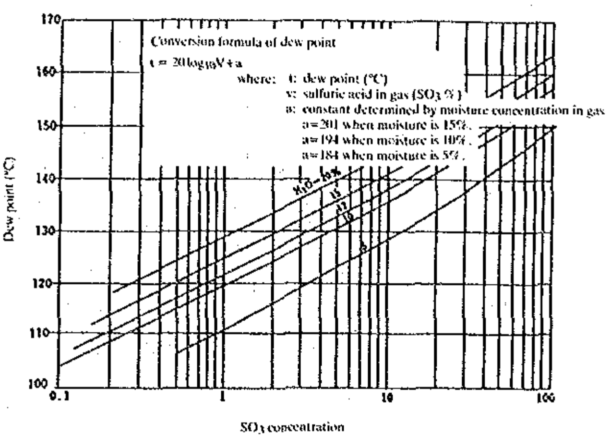


Fig. 2-2 Correlation between SO_3 Concentration and Dew Point

2.2.3 Stack Height and Diameter

When the stack diameter is determined, pressure loss and effective draft are the main factors. If they are unknown, however, it is empirically considered economical to arrange the flow rate at the stack outlet to be 10 to 20 m/s. In this study, therefore, the stack height has been calculated based on the factors that the stack flow rate is 15 m/s and the K value is 13. The fractions in calculation were rounded up to the unit of 0.5 m. The height set for each stack is shown in Table 2-1.

2.3 Expenses for Making Stacks Taller

The expenses to be incurred for making stacks taller has been calculated based on the prerequisites in Section 2.2 as shown in Table 2-2. While the expenses include the costs for the material, assembly, and thermal insulation/coating of stacks, the costs for foundation work are not included because of unknown geological features. As shown in Fig. 2-3, in addition, the stacks will be all replaced with new ones, with no attention paid to the presence of location space for remodeling of the existing stacks and installation of new ones. According to Table 2-2, in the case that 49 stacks are renewed to be made taller, it will cost approximately 115 million baht, proving that simply making stacks taller will unavoidably require a large amount of investment. Although no operating cost is necessary, furthermore, coating of the outer shell will be required to be done once every 5 to 10 years.

Table 2-2 Expenses for Making Stacks Taller

SEQ	County code	Factory No.	Stack No.	Gas temper-ature T (°K)	Normal exhaust gas volume Q (m^3/S)	Normal SO_2 emission volume q (Nm^3/h)	New Stack		Cost ($\times 10^3$ Bahts)
							Dia (m)	Height H_o (m)	
1)	3	75	1	313	26.092	31.697	1.55	38.0	8,100
2)	3	34	3	350	2.935	5.610	0.55	17.0	2,000
3)	2	23	4	350	2.697	3.281	0.53	12.5	1,400
4)	1	68	2	462	6.712	28.970	0.96	37.0	6,150
5)	3	23	5	333	4.349	2.633	0.65	10.0	1,300
6)	3	24	1	462	0.350	1.812	0.22	10.5	900
7)	2	24	2	437	0.157	0.186	0.14	3.0	85
8)	3	96	1	350	5.849	4.548	0.78	13.0	2,050
9)	3	33	2	437	0.007	0.971	0.03	8.5	450
10)	1	39	1	462	2.940	18.078	0.63	31.5	3,700
11)	2	19	2	523	0.519	2.019	0.28	10.5	1,050
12)	3	97	1	318	0.125	0.652	0.11	6.5	450
13)	1	68	1	462	1.860	8.047	0.50	21.0	2,300
14)	1	66	1	453	1.570	6.206	0.46	18.5	1,700
15)	3	59	2	443	1.852	6.647	0.49	19.0	1,950
16)	3	111	2	496	6.119	24.545	0.95	33.0	5,600
17)	1	56	2	448	1.482	2.703	0.44	11.0	1,200
18)	3	14	1	483	4.587	16.464	0.81	27.5	4,250
19)	3	14	2	483	4.587	16.464	0.81	27.5	4,250
20)	3	109	2	462	0.926	4.858	0.36	17.0	1,550
21)	3	90	1	462	0.932	3.649	0.36	14.5	2,400
22)	1	70	3	437	1.639	2.567	0.46	10.5	1,300
23)	1	35	2	483	1.305	5.895	0.43	18.0	1,650
24)	3	54	1	448	1.864	9.730	0.50	23.5	2,400
25)	1	35	1	483	1.305	5.857	0.43	18.0	1,650
26)	3	16	4	473	1.813	9.512	0.50	23.0	2,350
27)	3	102	1	462	2.319	9.008	0.56	21.5	2,300
28)	1	68	3	462	2.237	9.657	0.55	22.5	2,300
29)	1	66	2	453	2.223	8.796	0.54	21.5	2,300
30)	3	16	3	473	1.449	7.608	0.45	20.5	2,150
31)	3	47	3	498	2.025	7.922	0.55	20.0	2,150
32)	1	2	1	473	1.778	6.381	0.50	18.0	1,700
33)	3	109	1	462	1.237	6.478	0.41	19.5	1,900
34)	1	64	1	462	0.667	2.609	0.30	12.0	1,100
35)	1	70	2	573	5.406	16.113	0.96	23.5	4,400
36)	3	5	2	523	9.631	27.299	1.22	29.5	7,100
37)	3	16	1	473	1.086	5.692	0.39	18.0	1,650
38)	3	16	2	473	1.086	5.692	0.39	18.0	1,650
39)	1	70	1	573	4.317	12.890	0.85	21.5	4,000
40)	3	54	2	473	1.864	9.730	0.51	23.0	2,600
41)	3	54	3	473	1.864	9.730	0.51	23.0	2,600
42)	3	110	2	462	0.556	1.994	0.28	10.5	950
43)	2	5	6	462	0.608	2.226	0.29	11.5	1,000
44)	3	28	1	462	0.445	1.979	0.25	11.0	950
45)	1	55	1	393	4.230	22.098	0.70	35.5	3,900
46)	1	55	2	393	4.230	22.098	0.70	35.5	3,900
47)	3	14	3	483	2.293	8.232	0.57	20.0	2,150
48)	1	64	2	462	0.196	0.622	0.16	6.0	100
49)	3	95	2	333	1.141	0.886	0.33	7.0	200

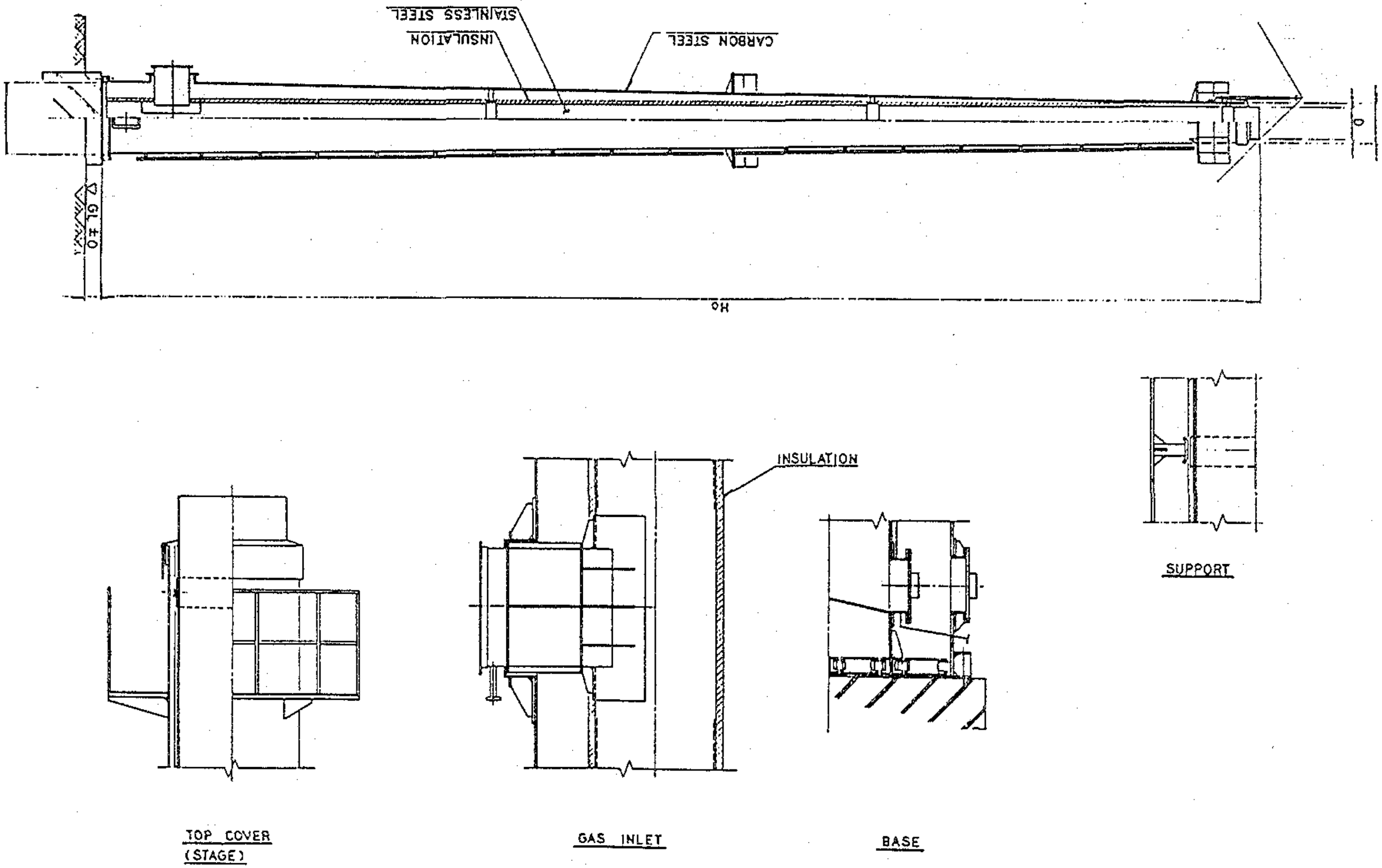


Fig. 2-3 Structure of Stacks

3. Improvement of SO_x Emission Sources Other than Making Stacks Taller

In the case that remedies at emission sources are worked out with K value regulation as a prerequisite, a possible way other than making stacks taller is to reduce the emission volume of SO_2, having the following three specific methods: ① fuel oil desulfurization to reduce the sulfur content of fuel to be used; ② conversion of fuel to a low sulfure type; and ③ flue gas desulfurization to remove SO_2 in emission gas generated. With reference to the said three methods, the outline of the systems will be hereunder described, coupled with roughly estimated costs when they are applied.

3.1 Desulfurization of Fuel Oil (Heavy Oil)

The technics for fuel oil desulfurization include the use of microorganism, irradiation of radioactivity, metal oxides, and catalytic hydrodesulfurization. For the present, however, hydrodesulfurization alone can be performed technically and economically. Currently, hydrodesulfurization of fuel oil being industrially put into practice can be roughly divided into three methods, direct desulfurization, indirect desulfurization, and a modified indirect desulfurization combining both. Fig. 3-1 to 3-3 show the system diagrams of these methods.

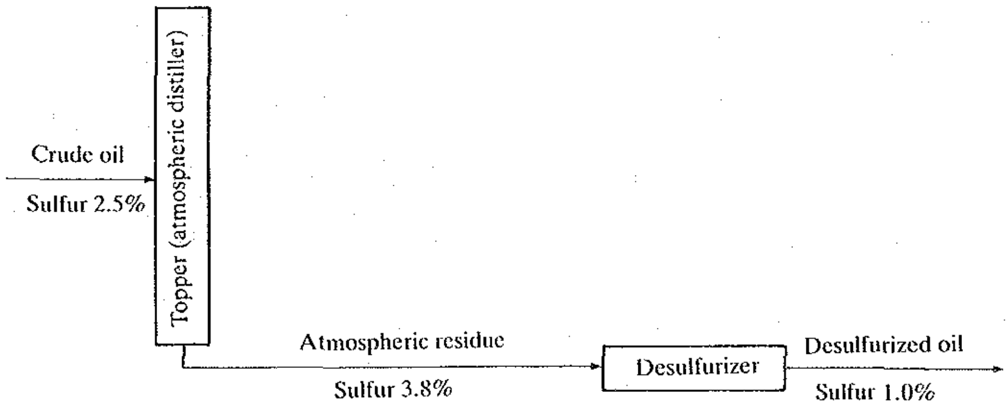


Fig. 3-1 Direct Desulfurization

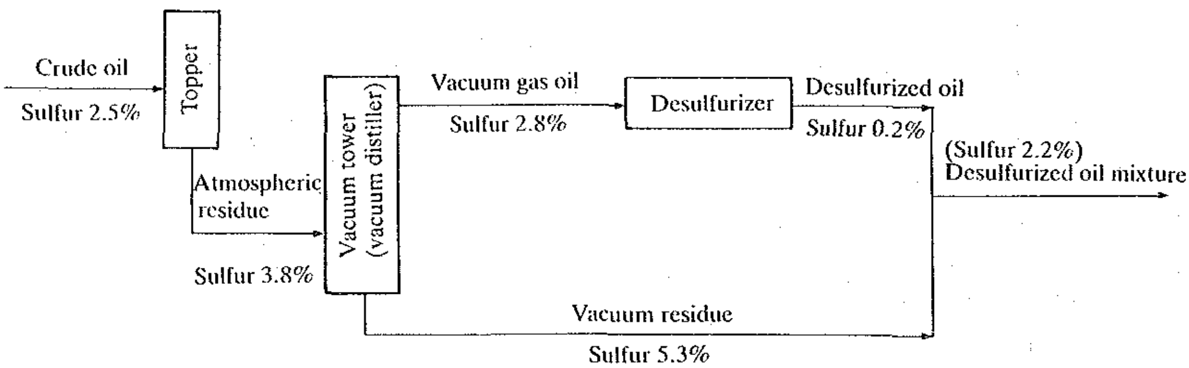


Fig. 3-2 Indirect Desulfurization

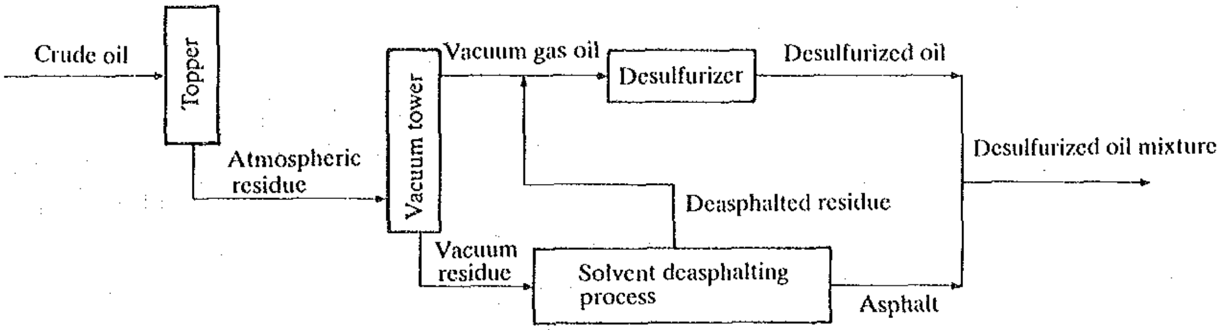


Fig. 3-3 Modified Indirect Desulfurization

3.1.1 Direct Desulfurization

In this method, the still residue (atmospheric residue) of an atmospheric distiller is introduced into a desulfurizer as it is and is then hydrodesulfurized under high temperature, high pressure, and the presence of a catalyst, reportedly enabling about 75% to be desulfurized. This method can be roughly divided into two types, namely, fixed bed and fluidized bed, depending on whether the catalyst to be used is fixed or fluidized inside the reactor. In both types reaction takes place at a reaction temperature of 350°C to 450°C, a reaction pressure of 50 kg/cm^2 to 200 kg/cm^2, and a liquid hourly space velocity (LHSV) of around 1.0. Generally the fluidized bed type is favorable for fuel oil containing an abundant asphaltene content and metallic components such as vanadium. As seen in Table 3-1, however, this type is not too desirable when there is great demand for fuel oil because produced oil becomes lighter compared with the fixed bed.

Table 3-1 Typical Products Yield and Property of Fluidized Bed and Fixed Bed (Quwait atmospheric residue; Sulfur 3.8 wt%)

	Fluidized bed	fixed bed
Products yield (Vol%)		
Gas, LPG	1.5 (Wt%)	0.4 (Wt%)
Naphtha	4.3	1.2
Middle fraction	17.6	10.0
Residue	79.5 (S=1.0 Wt%)	90.5 (S=1.0 Wt%)
Hydrogen consumption (Nm^3/kℓ)	113	123

3.1.2 Indirect Desulfurization

By this method atmospheric residue is once vacuum distilled to be separated between vacuum gas oil containing small amounts of catalyst poisoned substances (for example, asphalten content, and organic metallic compounds such as vanadium and nickel) and vacuum residue in the form of their concentration. Then, vacuum residue is mixed with desulfurized oil obtained as a result of hydrodesulfurizing only the vacuum gas oil which is easily desulfurized, resulting in the production of a low sulfur oil. As a consequence, the rate of desulfurization is as high as 90% to 95% in light of vacuum gas oil, whereas the said rate is about 40% to 45% in light of atmospheric residue.

3.1.3 Modified Indirect Desulfurization

While modified indirect desulfurization is an intermediate method between direct and indirect desulfurization, it can be said to belong to indirect desulfurization in that it separates asphalt content. As shown in Fig. 3-3, this method is the same as indirect desulfurization up till the process of vacuum distilling atmospheric residue to separate vacuum gas oil from vacuum residue. In accordance with this method, however, vacuum residue is further treated with propane or the other solvent to be separated between soluble and insoluble contents. This soluble content (deasphalted oil) is desulfurized together with vacuum gas oil and is mixed with the insoluble content (deasphalted residue), thus resulting in the production of final desulfurized oil. The application of this method enables desulfurization to the extent that the final sulfur content will become about 1.5% (about 60% in terms of the desulfurization rate).

3.1.4 Fuel Oil Desulfurization as a Improvement of Emission Sources

When fuel oil is desulfurized as a improvement of emission sources, it is necessary to solve the problems specified below.

(1) Unification of fuels in use

As shown in Table 3-2, the fuels being used at the target facilities include A grade fuel oil, B grade fuel oil, C grade fuel oil, and light oil, as well as coal, and their sulfur contents are in the range from 1.2% to 3.5%. It is therefore necessary to unify fuels used by various firms into a fuel of the same kind.

(2) Whether necessary to modify facilities with fuel conversion

A question raised in the above (1) unification of fuels in use is whether fuel conversion can be attained without structural modification. Particularly in the case that general coal is used in the factories listed in the "1-39-1 (County Code-Factory No.-Stack No.)," it is thought that substantial modification of facilities will be required.

(3) Determination of desulfurization capacity

As understandable from the emission volume of SO_2 by stack required to fulfill K=13 shown in Table 3-3, about 50% reduction is necessary even if S=1.2% in the case of the factories listed in the "2-24-2." Accordingly, the specification of the fuel to be unified must be less than S=0.6%. For other facilities, however, desulfurization to the extent that S=0.6% is not necessary because otherwise it would result in facilities with over-capacity. When desulfurization capacity (especially for the sulfur content of a product) is determined, consequently, it will be necessary to find an optimum point, in which case for some facilities, desulfurization should be performed concurrently with other countermeasures for emission sources.

Table 3-2 Quality and Consumption Volume of Fuel for the Facilities at which K=13 must be Achieved

SEQ	County code	Factory No.	Stack No.	Fuel	Sulfur content (%)	Specific gravity	Calory (Kcal/kg)	Fuel consumption (ℓ/H)	SG=0.95 10.300 Kcal/kg equivalent
1)	3	75	1	AHO	2.00	0.9408	10.430	2,400	2,406
2)	3	34	3	AHO	3.00	0.9850	10.000	270	272
3)	2	23	4	AHO	2.00	0.9408	10.000	248	238
4)	1	68	2	CHO	3.00	0.9561	10.296	1,440	1,449
5)	3	23	5	AHO	2.00	0.9408	10.430	200	201
6)	3	24	1	CHO	3.50	0.9900	9,900	75	75
7)	2	24	2	L.O	1.20	0.8660	10,950	25	24
8)	3	96	1	AHO	1.28	0.9462	10.000	538	520
9)	3	33	2	L.O	1.20	0.8700	10.950	1	1
10)	1	39	1	COAL	3.00	1.000	6,399	859 kg/H	562
11)	2	19	2	AHO	2.76	0.9358	10,495	111	111
12)	3	97	1	CHO	2.50	0.9529	10.340	40	40
13)	1	68	1	CHO	3.00	0.9561	10.296	399	401
14)	1	66	1	AHO	2.80	0.9383	10.394	337	329
15)	3	59	2	CHO	2.50	0.9529	10.340	398	401
16)	3	111	2	CHO	2.50	0.9529	10.340	375	378
					3.50	0.9900	9.900	375	376
					3.50	0.9900	10.495	375	398
17)	1	56	2	AHO	1.28	0.9462	10.000	318	306
18)	3	14	1	CHO	2.50	0.9529	10.340	984	991
19)	3	14	2	CHO	2.50	0.9529	10.340	984	991
20)	3	109	2	CHO	3.50	0.9950	9.900	199	200
21)	3	90	1	CHO	2.66	0.9764	10.400	200	208
22)	1	70	3	L.O	1.50	0.9200	10.950	266	274
23)	1	35	2	AHO	2.92	0.9500	10.518	280	286
24)	3	54	1	CHO	3.50	0.9900	9,900	400	401
25)	1	35	1	AHO	2.92	0.9500	10.518	280	286
26)	3	16	4	CHO	3.50	0.9950	9,900	389	392
27)	3	102	1	AHO	2.76	0.9358	10,495	498	500
28)	1	68	3	CHO	3.00	0.9561	10,296	480	483
29)	1	66	2	AHO	2.80	0.9383	10.394	477	475
30)	3	16	3	CHO	3.50	0.9950	9.900	311	313
31)	3	47	3	CHO	2.66	0.9764	10.400	435	451
32)	1	2	1	CHO	2.50	0.9529	10.340	382	385
33)	3	109	1	CHO	3.50	0.9950	9,900	266	268
34)	1	64	1	CHO	2.66	0.9764	10.400	143	148
35)	1	70	2	CHO	3.50	0.9900	9.900	663	664
36)	3	5	2	AHO	2.00	0.9408	10.430	2,067	2,073
37)	3	16	1	CHO	3.50	0.9950	9,900	233	235
38)	3	16	2	CHO	3.50	0.9950	9.900	233	235
39)	1	70	1	CHO	3.50	0.9900	9,900	529	530
40)	3	54	2	CHO	3.50	0.9900	9,900	400	401
41)	3	54	3	CHO	3.50	0.9900	9,900	400	401
42)	3	110	2	CHO	2.50	0.9529	10.340	119	120
43)	2	5	6	BHO	2.50	0.9750	10.000	130	130
44)	3	28	1	AHO	3.00	0.9850	10.000	95	96
45)	1	55	1	CHO	3.50	0.9900	10.336	908	950
46)	1	55	2	CHO	3.50	0.9900	10.336	908	950
47)	3	14	3	CHO	2.50	0.9529	10.340	492	495
48)	1	64	2	AHO	2.16	0.9609	10.461	42	43
49)	3	95	2	CHO	2.50	0.9529	10.340	52	52

Table 3-3 SO_2 Emission Volume Required to Fulfill K=13

SEQ	County code	Factory No.	Stack No.	Gas temperature T (°K)	Normal exhaust gas volume Q (m^3/S)	Normal SO_2 emission volume q (Nm^3/h)	SO_2 emission volume at K=13.0 q (Nm^3/h)
1)	3	75	1	313	26.092	31.697	4.576
2)	3	34	3	350	2.935	5.610	1.076
3)	2	23	4	350	2.697	3.281	1.001
4)	1	68	2	462	6.712	28.970	10.990
5)	3	23	5	333	4.349	2.633	1.139
6)	3	24	1	462	0.350	1.812	0.809
7)	2	24	2	437	0.157	0.186	0.089
8)	3	96	1	350	5.849	4.548	2.199
9)	3	33	2	437	0.007	0.971	0.472
10)	1	39	1	462	2.940	18.078	9.144
11)	2	19	2	523	0.519	2.019	1.026
12)	3	97	1	318	0.125	0.652	0.337
13)	1	68	1	462	1.860	8.047	4.164
14)	1	66	1	453	1.570	6.206	3.303
15)	3	59	2	443	1.852	6.647	3.562
16)	3	111	2	496	6.119	24.545	13.428
17)	1	56	2	448	1.482	2.703	1.703
18)	3	14	1	483	4.587	16.464	10.600
19)	3	14	2	483	4.587	16.464	10.600
20)	3	109	2	462	0.926	4.858	3.225
21)	3	90	1	462	0.932	3.649	2.466
22)	1	70	3	437	1.639	2.567	1.748
23)	1	35	2	483	1.305	5.895	4.082
24)	3	54	1	448	1.864	9.730	6.761
25)	1	35	1	483	1.305	5.857	4.082
26)	3	16	4	473	1.813	9.512	6.674
27)	3	102	1	462	2.319	9.008	6.379
28)	1	68	3	462	2.237	9.657	7.054
29)	1	66	2	453	2.223	8.796	6.480
30)	3	16	3	473	1.449	7.608	5.822
31)	3	47	3	498	2.025	7.922	6.110
32)	1	2	1	473	1.778	6.381	4.952
33)	3	109	1	462	1.237	6.478	5.184
34)	1	64	1	462	0.667	2.609	2.105
35)	1	70	2	573	5.406	16.113	13.485
36)	3	5	2	523	9.631	27.299	23.780
37)	3	16	1	473	1.086	5.692	5.022
38)	3	16	2	473	1.086	5.692	5.022
39)	1	70	1	573	4.317	12.890	11.407
40)	3	54	2	473	1.864	9.730	8.699
41)	3	54	3	473	1.864	9.730	8.699
42)	3	110	2	462	0.556	1.994	1.812
43)	2	5	6	462	0.608	2.226	2.028
44)	3	28	1	462	0.445	1.979	1.822
45)	1	55	1	393	4.230	22.098	20.695
46)	1	55	2	393	4.230	22.098	20.695
47)	3	14	3	483	2.293	8.232	7.771
48)	1	64	2	462	0.196	0.622	0.606
49)	3	95	2	333	1.141	0.886	0.871

(4) Determination of processing volume

About 3500 barrels/day is the processing volume of fuel oil at the factories (shown in Table 3-2) which require countermeasures for reduction of SO_2. If this volume is regarded as the processing capacity, however, the fuel oil desulfurization facilities for 3500 barrels/day are to serve only these 49 facilities, leading to the necessity of solving the problem of locations, construction funds, or processing cost.

Since there are, as described above, many difficulties to be solved in the case of fuel oil desulfurization, this countermeasure may not be realistic for the present.

3.1.5 Expenses for Fuel Oil Desulfurization

The estimation of expenses roughly calculated, for reference in comparison with other countermeasures, amounts to about 880 million baht. The prerequisites for this case are as specified below. The construction cost is for one set excluding that for foundation work. It was decided, however, that all requirements except for local construction would be supplied from Japan.

① Properties of fuel oil
S=3.0%
SG=0.95
Caloric value=10300 Kcal/kg

② Sulfur content after desulfurization
S=0.6 (desulfurization rate: 80%)

③ Desulfurization method
Direct desulfurization (to manage a high rate of desulfurization)

④ Processing volume
3500 barrels/day

3.2 Fuel Conversion

Most of the target facilities are using fuel oil. When the fuel is changed over to another type by fuel conversion, possible candidates will be natural gas, LPG and lignite. Based on discussion with ONEB, however, fuel conversion to natural gas is hereunder reviewed.

3.2.1 Properties of Natural Gas

Among naturally occurring gases, those combustible gases containing hydrocarbon as the major ingredient are commonly called natural gas, including oil field gas, gas field gas, and coal field gas, and are classified into oil soluble type, water soluble type, and free type depending upon the conditions of the gas layer forming a deposit. As shown in Table 3-4, in addition, the properties of gas lead to the major classification of dry gas and wet gas. The former is defined as a gas whose combustible content is almost composed of CH_4, while the latter is defined as a gas which contains a considerable volume of C_3H_8 heavier other than CH_4 and C_2H_6. The caloric values are about 9000 to 9300 $Kcal/Nm^3$ and 10400 to 12200 $Kcal/Nm^3$, respectively.

Table 3-4 Properties of Natural Gas

	Ingredient (in %)										High caloric value
					C_nH_{2n+2}						
	CO_2	O_2	CO	H_2	C_1	C_2	C_3	C_4	N_2	S	$Kcal/Nm^3$
Dry	3.4	0.1	—	—	94.6	—	—	—	1.9	—	9000
Wet	0.7	—	—	—	75.4	13.6	7.5	2.8	—	—	12200

3.2.2 Characteristics of Gas Combustion

As compared with the combustion of fuel oil, gas combustion has the following characteristics:

① Adjustment of combustion can be performed promptly and accurately and is suited for automatic control.

② Flame is stable regardless of the condition of the combustion chamber, yielding a high combustion efficiency.

③ It reduces excess air, facilitating the adjustment of atmosphere inside the furnace.

④ Concomitant use of many small-size burners makes it easy to freely adjust temperature distribution inside the furnace in terms of space or timing.

⑤ There are no harmful effects of ash and carbon accumulation on combustion chamber, burner, heated matter, and flue.

⑥ Facility cost including piping work is high.

⑦ Radiant heat is small, with a low temperature of combustion chamber.

⑧ It is in danger of causing sanitary harm and explosion due to the CO content of gas or CO produced by incomplete combustion.

3.2.3 Fuel Conversion as a Improvement of Emission Sources (Natural Gas)

In the case that fuel conversion to natural gas is performed as a improvement of emission sources, the following problems should be solved:

(1) Change in the capacity of combustion facilities accompanied by fuel conversion

Because of the small radiant heat of natural gas in comparison with fuel oil combustion as described in the item ⑦ of the preceding paragraph 3.2.2, especially the case of a steam boiler entails a possibility that there may be a decline in evaporation ability to meet the same input calorie. As a consequence, in the case of a factory in which the current facilities are almost in full operation, the fuel conversion to natural gas must be examined cautiously.

(2) Supply and storage of fuel

While the supply of natural gas is generally carried out through pipelines, if there is a distance between production facilities and the facilities in use, there are such requirements as the installation of a gas holder in the middle, thus incurring the facility cost as mentioned in the item ⑥ of the preceding paragraph 3.2.2. It is therefore necessary to clarify in advance who will bear this cost, and how. In regard to storage, on the other hand, it may be necessary to provide storage facilities individually depending upon the situation of each user.

3.2.4 Expenses for Fuel Conversion to Natural Gas

The required expenses varies substantially, as described in the previous section, depending upon the view of burdens stemming from the facilities including production facilities up to the gas holder. Assuming the modification of everything at the steam boiler, consequently, herein calculated was the expenses to be incurred purely for modification of burners and their surroundings except for the facility cost of the supply side. The results are shown in Table 3-5. The scope of modification work is specified below. For reference, in addition, Fig. 3-4 to Fig. 3-6 show a system diagram of a burner unit for fuel oil and gas and an illustration of a gas burner unit.

① Removal of existing burners
② Removal of oil pipe with an existing wind box mounted
③ Removal of oil spray steam pipe with an existing wind box mounted
④ Removal of existing spray fuel units
⑤ Installation of new gas burners
⑥ Electric wiring work
⑦ Gas piping work

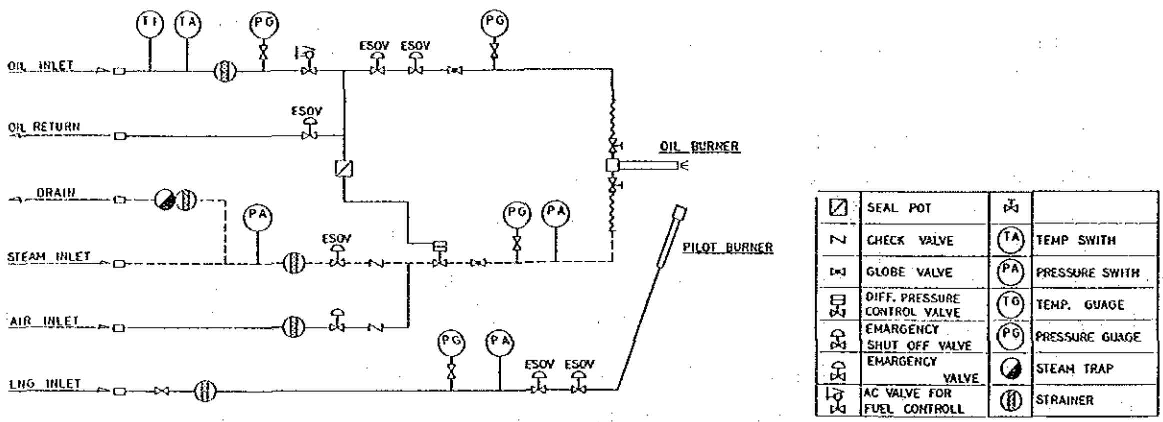


Fig. 3-4 System Diagram of Fuel Oil Burners

Table 3-5 Expenses for Fuel Conversion

SEQ	County code	Factory No.	Stack No.	Fuel	Sulfur content (%)	Specific gravity	Calory (Kcal/kg)	Fuel consumption (ℓ/H)	Cost ($\times 10^3$ Bahts)
1)	3	75	1	AHO	2.00	0.9408	10,430	2,400	2,280
2)	3	34	3	AHO	3.00	0.9850	10,000	270	1,340
3)	2	23	4	AHO	2.00	0.9408	10,000	248	1,340
4)	1	68	2	CHO	3.00	0.9561	10,296	1,440	1,950
5)	3	23	5	AHO	2.00	0.9408	10,430	200	1,340
6)	3	24	1	CHO	3.50	0.9900	9,900	75	1,180
7)	2	24	2	L.O	1.20	0.8660	10,950	25	1,180
8)	3	96	1	AHO	1.28	0.9462	10,000	538	1,470
9)	3	33	2	L.O	1.20	0.8700	10,950	1	1,180
10)	1	39	1	COAL	3.00	1.000	6,399	859 kg/H	1,470
11)	2	19	2	AHO	2.76	0.9358	10,495	111	1,180
12)	3	97	1	CHO	2.50	0.9529	10,340	40	1,180
13)	1	68	1	CHO	3.00	0.9561	10,296	399	1,470
14)	1	66	1	AHO	2.80	0.9383	10,394	337	1,400
15)	3	59	2	CHO	2.50	0.9529	10,340	398	1,470
16)	3	111	2	CHO	2.50	0.9529	10,340	375	4,270
					3.50	0.9900	9,900	375	
					3.50	0.9900	10,495	375	
17)	1	56	2	AHO	1.28	0.9462	10,000	318	1,400
18)	3	14	1	CHO	2.50	0.9529	10,340	984	6,230
19)	3	14	2	CHO	2.50	0.9529	10,340	984	6,230
20)	3	109	2	CHO	3.50	0.9950	9,900	199	1,340
21)	3	90	1	CHO	2.66	0.9764	10,400	200	1,340
22)	1	70	3	L.O	1.50	0.9200	10,950	266	1,340
23)	1	35	2	AHO	2.92	0.9500	10,518	280	1,340
24)	3	54	1	CHO	3.50	0.9900	9,900	400	1,470
25)	1	35	1	AHO	2.92	0.9500	10,518	280	1,340
26)	3	16	4	CHO	3.50	0.9950	9,900	389	1,470
27)	3	102	1	AHO	2.76	0.9358	10,495	498	1,470
28)	1	68	3	CHO	3.00	0.9561	10,296	480	1,470
29)	1	66	2	AHO	2.80	0.9383	10,394	477	1,470
30)	3	16	3	CHO	3.50	0.9950	9,900	311	1,400
31)	3	47	3	CHO	2.66	0.9764	10,400	435	1,470
32)	1	2	1	CHO	2.50	0.9529	10,340	382	1,400
33)	3	109	1	CHO	3.50	0.9950	9,900	266	1,340
34)	1	64	1	CHO	2.66	0.9764	10,400	143	1,340
35)	1	70	2	CHO	3.50	0.9900	9,900	663	1,600
36)	3	5	2	AHO	2.00	0.9408	10,430	2,067	2,280
37)	3	16	1	CHO	3.50	0.9950	9,900	233	1,340
38)	3	16	2	CHO	3.50	0.9950	9,900	233	1,340
39)	1	70	1	CHO	3.50	0.9900	9,900	529	1,470
40)	3	54	2	CHO	3.50	0.9900	9,900	400	1,470
41)	3	54	3	CHO	3.50	0.9900	9,900	400	1,470
42)	3	110	2	CHO	2.50	0.9529	10,340	119	1,340
43)	2	5	6	BHO	2.50	0.9750	10,000	130	1,340
44)	3	28	1	AHO	3.00	0.9850	10,000	95	1,340
45)	1	55	1	CHO	3.50	0.9900	10,336	908	1,790
46)	1	55	2	CHO	3.50	0.9900	10,336	908	1,790
47)	3	14	3	CHO	2.50	0.9529	10,340	492	1,470
48)	1	64	2	AHO	2.16	0.9609	10,461	42	1,180
49)	3	95	2	CHO	2.50	0.9529	10,340	52	1,180

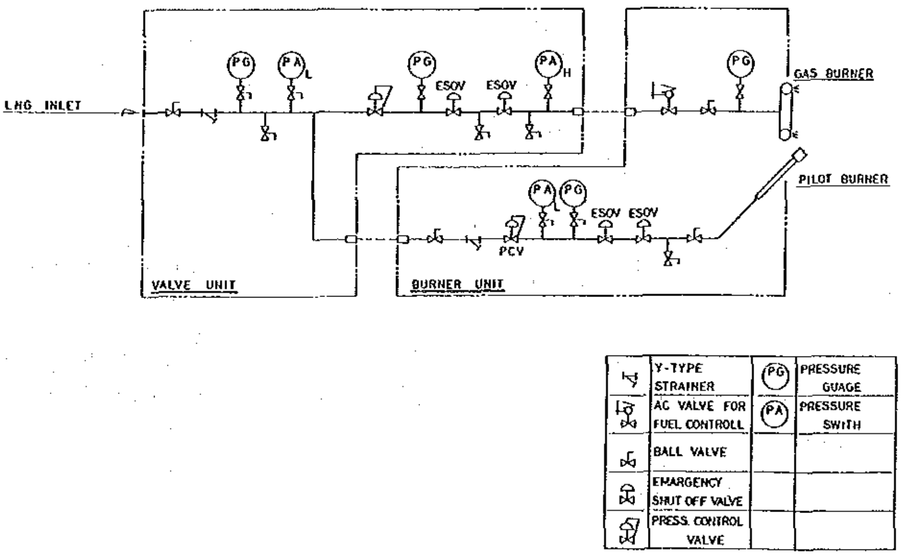
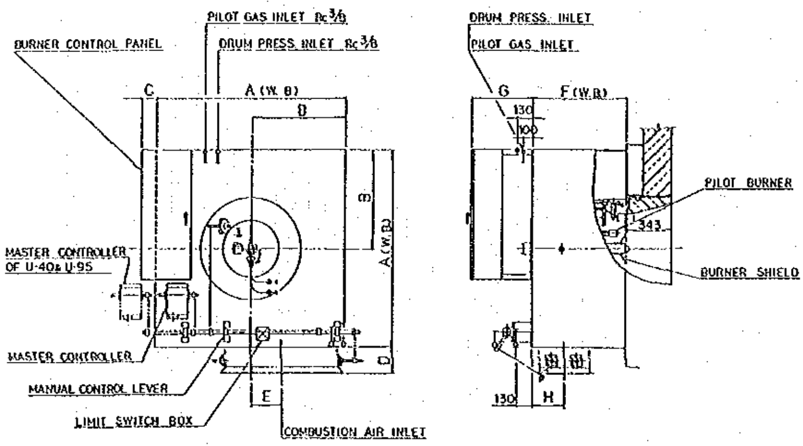


Fig. 3-5 System Diagram of LNG Burners



MARK / TYPE	A	B	C	D	E	F	G	H	OIL INLET	STEAM INLET	ATOMIZING AIR INLET
U-40NF	715	457.5	200	200	130	450	500	170	Rc 1/2	Rc 1/2	Rc 1/2
U-95NF	1220	610	200	200	200	762	500	253	Rc 1	Rc 1	Rc 1
U-85NF	1524	762	126	200	250	762	500	260	Rc 1	Rc 1 1/4	Rc 1 1/4
U-65NF (1)	1830	915	70	200	100	920	500	260	Rc 1 1/4	Rc 1 1/4	Rc 1 1/4
U-65NF (2)	1830	915	70	200	100	920	500	360	Rc 1 1/4	Rc 1 1/4	Rc 1 1/4
U-60NF	1980	990	70	200	0	1220	500	470	Rc 1 1/2	Rc 1 1/2	Rc 1 1/2

Fig. 3-6 Illustration of Gas Burner Unit

3.3 Flue Gas Desulfurization

The countermeasures for stationary emission sources include flue gas desulfurization to remove sulfur oxides from flue gas, in line with conversion to low sulfur fuels and fuel oil desulfurization. This method allows flue gas to contact an absorbent or adsorbent or to be oxidized with a catalyst, and recovers or removes a sulfur oxide in the form of sulfite, sulfate or sulfuric acid. The recovered materials include gypsum, ammonium sulfate, sodium sulfate, sodium sulfite, sulfuric acid, and sulfur.

3.3.1 Classification of Flue gas Desulfurization

There are many kinds and classifications of flue gas desulfurization. This method is roughly divided into absorption, absorption and catalytic oxidation, with the absorption method being further classified into wet and dry processes. By the absorption method, chemicals that react easily with sulfite gas are used as an absorbent to contact flue gas, leading to the separation of sulfite gas from flue gas to recovery in the form of liquid or solid compounds. The absorption method is further classified as follows:

(1) Wet process

The wet process includes a solution method in which the absorbent is dissolved in water and a slurry method in which the absorbent is suspended in water. The solution method is classified into such methods as caustic soda, sodium sulfite, ammonium, and dilute sulfuric acid, depending upon the types of absorbent. The slurry method is likewise classified into a lime method and a magnesium hydroxide method. The wet process is a method in which flue gas is washed with a solution or slurry to remove the sulfur oxide from flue gas in the form of sodium sulfite or sodium sulfate. This method has been put to practical use to treat flue gas from boilers and tail gas from such facilities as sulfuric acid plants. At present, the wet process is most popular among the methods of flue gas desulfurization. This process has advantages of a high rate of desulfurization and easy operation, and can be also applied for treatment of flue gas containing a high concentration of sulfite gas, whereas the use of water causes a decrease in the temperature of flue gas, leading to the poor diffusion of smoke. Consequently, some treatment has been added, for example, burning the waste gas.

(2) Dry process

Using various oxides including alkaline earth metals, alkali metals, and manganese as the absorbent, this method removes the sulfur oxide compounds of flue gas in the form of sodium sulfate through solid and gas phase reaction. The adsorption method allows about 100°C flue gas to pass through an activated carbon. In this method the adsorbed sulfite gas becomes sulfate anhydride through reaction with oxygen and then becomes sulfuric acid through reaction with vapor, thus being adsorbed. Activated carbon which has deadsorbed sulfuric acid is repeatedly used for desulfurization.

The catalytic oxidation is a process in which sulfite gas is catalytically oxidized with a catalyst of vanadium pentaoxide to obtain sulfate anhydride. This reaction is also used as a process of catalytic sulfate production. A method which applies this reaction to remove the sulfite gas from flue gas in the form of sulfate anhydride is called the catalytic oxidation process. The catalytic oxidation of sulfite gas is performed at 450 °C to 470 °C.

3.3.2 Wet Absorption Process

(1) Use of lime slurry as absorbent

$CaCO_3$, $Ca(OH)_2$, carbide waste, etc. are smashed to about 200 meshes or less to be used as 5% to 15% slurry, with which flue gas is washed. Sulfite gas is converted to calcium sulfite. This is oxidized by air and recovered or removed in the form of gypsum. The rate of desulfurization varies depending upon the pH of the solution; the rate of desulfurization is high at a high pH, but accompanies concern about scaling.

(2) Use of magnesium hydroxide slurry as absorbent

Magnesium sulfite or magnesium sulfate is obtained by reaction with sulfite gas. With part of the absorbent extracted from the circulation system, the absorbent is regenerated by thermal decomposition after being dried, and simultaneously, the resulting concentrated sulfite gas is used as a raw material for sulfuric acid or recovered as liquid SO_2.

(3) Use of aqueous ammonium solution as absorbent

Since an aqueous ammonium solution has a high partial pressure of ammonium, undergoing loss accompanied by waste gas, the common practice is to be absorbed by sulfite gas to form an aqueous solution of sulfite ammonium. Thus, it absorbs sulfite gas and generates ammonium hydrogensulfite. With ammonium and water added to the absorbing solution which after leaving absorption tower, the said solution recirculates, but partly being fed to the recovery process. The ways of recovery include: ① recovering ammonium sulfate and concentrated sulfite gas by adding sulfuric acid; ② adding ammonium to obtain ammonium sulfite and then oxidizing with pressurized air to recover ammonium sulfate; ③ adding sulfuric acid and heating at 150°C, 5 kg/cm^2 to recover sulfur and ammonium sulfate; and ④ adding limestone or $Ca(OH)_2$ to recover gypsum, regenerating ammonium.

(4) Use of caustic soda or sodium sulfite as absorbent

There are the following two methods: sulfite gas is absorbed using caustic soda or sodium sulfite as the absorbing solution, and the resulting sodium hydrogensulfite is treated for recovery or removal as sodium sulfate, sodium sulfite, and gypsum; and the above sodium hydrogensulfite is treated to recover sulfite gas. For regeneration of the absorbing solution, there are several available methods such as thermal decomposition by steam or adding caustic soda.

(5) Using dilute sulfuric acid as absorbent

In this process, dilute sulfuric acid with the addition of an oxidation catalyst as an absorbing solution is used to absorb sulfite gas and thus obtain sulfuric acid. Absorbing sulfite gas at a packed tower, the absorbing solution is oxidized by air to sulfuric acid at an oxidation tower, then circulated in an absorption tower. Part of it is extracted and fed to a crystallizing vessel for reaction with limestone, followed by the recovery of gypsym.

3.3.3 Dry Absorption Process

(1) Addition of lime or dolomite in a furnace

Calcium oxide or magnesium oxide, which is produced by decomposition of limestone or dolomite at a high temperature, reacts with sulfite gas and oxygen to directly produce sulfate. While blowing the powder of limestone or dolomite, or $Ca(OH)_2$ into the combustion chamber of a boiler and transporting it with combustion gas, sulfite gas is fixed by the above mentioned reaction and is then collected with a dust collector. When the gas temperature at the blowing position is about 1050 °C, the best results can be obtained. The desulfurization rate is generally low, accounting for 20% to 40% in the case of addition in an amount equivalent to 1 to 2 times the theoretical value against sulfite gas. The adherence of the absorbent to the heating surface is a problem.

(2) Use of alkali absorbent

Porous alumina retaining an alkali metal oxide, or sodium carbonate (light soda ash) is added to about 300°C combustion flue gas, followed by the fixation of sulfite gas as sodium sulfate. The absorbent collected by the dust collector is reduced with about 600°C hydrogen to regenerate the absorbent as well as recover hydrogen sulfide. There is another method in which a fused carbonate mixture (containing lithium carbonate, sodium carbonate, and potassium carbonate) is used as an absorbent.

(3) Use of manganese oxide as absorbent

Highly active $MnO_x \cdot nH_2O$ (x=1.5 to 1.8, n=0.3 to 1.0) is used as an absorbent. After the absorbent in the form of fine grain is added to waste gas of 135°C to 150°C, sulfite gas is absorbed while being transported by flashing, and is fixed as manganese sulfate. It is then separated from flue gas with a dust collector. Most of the collected absorbent is recycled, part of it is extracted for air oxidation under the presence of aqueous ammonium, thus resulting in the recovery of ammonium sulfate as well as the regeneration of the absorbent.

3.3.4 Adsorption Process

In the activated carbon process using activated carbon as an adsorbent, a fixed bed, moving bed and fluidized bed are used to attain the contact between flue gas and activated carbon. Activated carbon is regenerated and repeatedly used, and the regeneration methods include wash deadsorption, thermal deadsorption, and steam deadsorption. Sulfite gas, being adsorbed by activated carbon, is recovered as concentrated sulfite gas, sulfuric acid, or gypsum. There are several units of packed tower with activated carbon, which repeat adsorbing, washing, and drying by valve switching. After dust is removed, flue gas passes through a tower for the drying cycle at 130°C to 145°C, drying the washed activated carbon. This allows gas with a lowered temperature to be mixed with the original gas and then fed to the tower for the adsorption cycle at about 100°C for desulfurization. Dilute sulfuric acid is obtained from the tower for the washing cycle. This is concentrated to sulfuric acid, or limestone is added, to recover gyprum. There is another method in which activated carbon is washed intermittently and then fed to the gas cooling tower to simultaneously carry out the cooling of flue gas and the concentration of sulfur. Still another method is available in which with activated carbon as the moving bed, sulfite gas is adsorbed through the counterflow or crossflow of waste gas with it, followed by deadsorption with oxygen-free gas or superheated steam of about 300°C.

3.3.5 Catalytic Oxidation Method

After dust in flue gas is removed with the dust collector, the gas is passed through a catalyst layer at 450 °C to 470 °C for oxidation of 90% of sulfite gas to sulfate anhydride. It is then cooled with an economizer or air preheater to adsorb sulfate mist, which occurs in the meantime, with sulfuric acid.

3.3.6 Other Methods

There are other methods including that in which sulfite gas in flue gas is reacted with hydrogen sulfide and is removed as sulfur; and that in which sulfite gas in flue gas is oxidized for removal as sulfuric acid by using a nitrogen oxide as a medium for oxygen transfer as in the manufacture of sulfuric acid by lead chamber process.

3.3.7 Cost for Flue Gas Desulfurization

There are, as described above, various methods in flue gas desulfurization. The cost for such desulfurization has been examined by setting the cases and wet process using caustic soda is adopted finally, because of the very small volume of flue gas by plant as shown in Table 3-3 and the process is most common and its absorbent is relatively easy to obtain. Table 3-6 and Figure 3-7 show the cost of each facility and a basic flowchart of desulfurization. The operating cost includes power and caustic soda, but not including water and sludge treatment charges. In addition, the desulfurization rate was set at a value during standard minimum operation (approximately equal to 85%) due to difficult control. The construction cost includes the cost for one set excluding stacks, control dumpers (including ducts) and civil work.

Table 3-6 Cost for Flue Gas Desulfurization

SEQ	County code	Factory No.	Stack No.	Gas temper-ature T (°K)	Normal exhaust gas volume Q (m^3/S)	Normal SO_2 emission volume q (Nm^3/h)	Running cost Bahts/H	Total cost (×10^3 Bahts)
1)	3	75	1	313	26.092	31.697	1,600	38,000
2)	3	34	3	350	2.935	5.610	320	11,500
3)	2	23	4	350	2.697	3.281	210	11,500
4)	1	68	2	462	6.712	28.970	1,420	16,700
5)	3	23	5	333	4.349	2.633	210	15,000
6)	3	24	1	462	0.350	1.812	120	7,500
7)	2	24	2	437	0.157	0.186	30	4,200
8)	3	96	1	350	5.849	4.548	300	16,700
9)	3	33	2	437	0.007	0.971	60	1,700
10)	1	39	1	462	2.940	18.078	870	11,500
11)	2	19	2	523	0.519	2.019	120	7,500
12)	3	97	1	318	0.125	0.652	60	4,200
13)	1	68	1	462	1.860	8.047	400	9,500
14)	1	66	1	453	1.570	6.206	330	9,500
15)	3	59	2	443	1.852	6.647	350	9,500
16)	3	111	2	496	6.119	24.545	1,220	16,700
17)	1	56	2	448	1.482	2.703	170	9,000
18)	3	14	1	483	4.587	16.464	830	15,000
19)	3	14	2	483	4.587	16.464	830	15,000
20)	3	109	2	462	0.926	4.558	260	7,700
21)	3	90	1	462	0.932	3.649	200	7,700
22)	1	70	3	437	1.639	2.567	170	9,500
23)	1	35	2	483	1.305	5.895	300	9,000
24)	3	54	1	448	1.864	9.730	480	9,500
25)	1	35	1	483	1.305	5.857	300	9,000
26)	3	16	4	473	1.813	9.512	310	9,500
27)	3	102	1	463	2.319	9.008	450	10,700
28)	1	68	3	462	2.237	9.657	490	10,700
29)	1	66	2	453	2.223	8.796	450	10,700
30)	3	16	3	473	1.449	7.608	380	9,500
31)	3	47	3	498	2.025	7.922	420	10,700
32)	1	2	1	473	1.778	6.381	340	9,500
33)	3	109	1	462	1.237	6.478	320	9,000
34)	1	64	1	462	0.667	2.609	150	8,000
35)	1	70	2	573	5.406	16.113	810	16,700
36)	3	5	2	523	9.631	27.299	140	21,000
37)	3	16	1	473	1.086	5.692	280	9,000
38)	3	16	2	473	1.086	5.692	280	9,000
39)	1	70	1	573	4.317	12.890	670	15,000
40)	3	54	2	473	1.864	9.730	480	10,700
41)	3	54	3	473	1.864	9.730	480	10,700
42)	3	110	2	462	0.556	1.994	110	7,500
43)	2	5	6	462	0.608	2.226	130	7,500
44)	3	28	1	462	0.445	1.979	110	7,000
45)	1	55	1	393	4.230	22.098	1,070	15,000
46)	1	55	2	393	4.230	22.098	1,070	15,000
47)	3	14	3	483	2.293	8.232	440	10,700
48)	1	64	2	462	0.196	0.622	50	5,400
49)	3	95	2	333	1.141	0.886	80	9,000

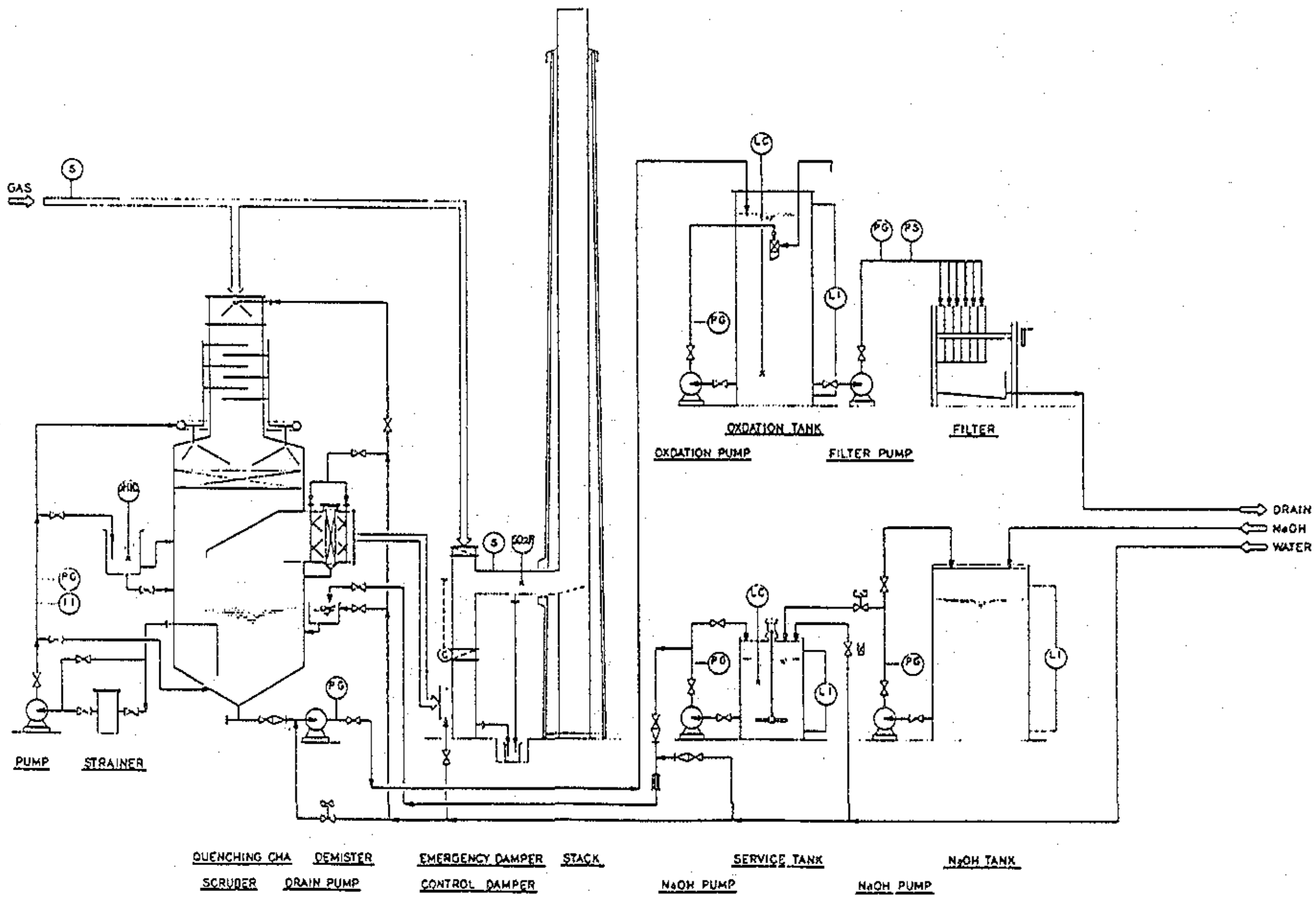


Figure 3-7 Flowchart of Flue Gas Desulfurization

3.4 Reduction of Fuel Consumption through Energy Saving

3.4.1 Effects of Energy Saving

Up to this point, we have been discussing countermeasures under the assumption that some kind of methods will be implemented. In reality, however, not all of the subject factories will be able to make the capital investments which are necessary. Even if they are able to make the investments, we do not believe that they will willingly invest in something which does not lead to greater profits. Therefore, methods which do not require large investments and which will bring some advantages must be promoted. The only such method is the reduction of fuel consumption through implementing energy saving countermeasures. Since energy saving does not make visible effect in short term but require continuous efforts in long term to get its effect, it is likely disregarded as the method. It is, however, most reliable method in spite of small investment when we examine from middle to long term point of view.

Table 3-7 shows some examples of energy saving countermeasures taken in Japan and their effects. This table shows the degree to which energy base units (total of energy consumption, such as the electric power necessary to manufacture products or profits per unit volume) have decreased (improved) in different industries through energy saving countermeasures. The table shows the figures for 1987 based on an index of 100 for the year 1973. From this table, there have been savings ranging from 20 to 40 percent over a 14 year period. This means that the yearly reductions have been from 1.5 to 3.0 percent per year. If these figures are applied to the Samut Prakarn industrial district and a reduction in fuel consumption of 15 to 30 percent in a ten year period is assumed, then the K-value=13 goal will be achieved at most facilities. Table 3-8 shows, for reference purposes, an outline of the energy usage rationalization criteria which the management of plants use.

3.4.2 Costs Involved in Energy Saving Countermeasures

Although the figures are ambitious, in regard to energy saving percentage by industry, the figures in Table 3-7 for energy saving percentage in Japan have been applied in Table 3-9 to show a yearly percentage. In this table, the general criteria in Japan for the amount of investment for energy saving countermeasures have been applied, that is, investment amount is equivalent to the saving amount over a three year period resulting from the energy saving countermeasures.

As a result, the calculations show that the amount of energy saved between 1993 to 1999 if energy saving countermeasures are taken at the 49 stacks (=combustion facilities) would be 65,500 kiloliters. If this is evaluated on the basis of the projected price of fuel oil for 1999 (3960 bahts/kl), then approximately 260 million bahts, or about 1.6 times the investment (160 million bahts) can be saved.

In addition, these energy saving countermeasures will lead to a reduction of about 11 percent for all fuel oil consumed (584,000 kl) by the manufacturing sector in the Samut Prakarn district in

1999. This also means that SO_2 emissions can be reduced by 11 percent.

Detail on investment in energy saving countermeasures and its effects are described in section 6.4 of Chapter 6.

Table 3-7 Status of Energy Saving Countermeasures in Energy Intensive Industries

(units: percent)

Industry	Energy (oil) base unit reduction status (FY1987/FY1973)	Outline of energy saving countermeasures	Representative energy saving facilities, etc.
Steel	77.2 (26.2)	① Improvements in operation technology. ② Recovery of waste energy. ③ Improvements in production processes. ④ Improvements in energy usage efficiency.	① Hot slab continuous casting machine. ② Low-pressure-loss-type blast furnace top pressure recovery power generating equipment ③ Coke dry type fire extinguishing equipment
Petrochemical (Ethylene division)	57.3 (Note) (76.0)	① Improvements in waste heat recovery. ② Rationalization of processes. ③ Reduction of circulation flow ratio in the distillation system.	① Waste heat recovery equipment for recovery of heat from waste gas from heating furnaces. ② Waste heat recovery equipment for recovery of heat from decomposed generated matter. ③ High efficiency compressors
Cement	69.7 (0)	① NSP conversion ② Improvements at raw masterial mills and finishing mills. ③ Utilization of waste heat. ④ More efficient combustion control.	① SP and NSP kilns ② Vertical mills ③ Power generation using medium and low temperature waste heast.
Paper, pulp	59.6 (45.0)	① Introduction of continuous production processes. ② Recovery of waste heat. ③ Greater efficiency in production processes. ④ Increased use of old paper.	① Spare immersion type continuous cooking devices. ② High performance pulp washing devices ③ High performance sizing press
Dying	63.7 (59.8)	① Introduction of thorough maintenance and control. ② Recovery and utilization of hot waste water and waste heat. ③ Introduction of energy saving equipment for textile dyeing, etc. ④ Improvements in fabrication conditions, etc.	① Spout-type dying machines ② Dye stuff economizer ③ Counterflow cleaning machines
Sheet glass	73.0 (67.7)	① Thermal insulation using insulating materials. ② Improvements in the sealing of ovens. ③ Improvements in heat storage efficiency. ④ Installation of waste heat boilers.	① Boilers which use waste heat.

(Note) The energy (petroleum) base units for the steel industry are figures from the fiscal years 1986 and 1973. The energy (petroleum) base units for the petrochemical industry (ethylene division) are figures from the fiscal years 1987 and 1976.

Table 3-8 Outlines of Energy Usage Rationalization Criteria Used by Managers Involved with Factories

	① Rationalization of the combustion of fuel	② Rationalization of heating, cooling and thermal transfer	③ Prevention of thermal loss through radiation, conduction, etc.	④ Recovery and usage of waste heat.	⑤ Rationalization of conversion of heat to power, etc.	⑥ Prevention of loss of electricity through resistance, etc.	⑦ Rationalization of conversion of electricity to power, heat, etc.
Establishment of standards for improvement of control standards.	Control standards for air ratios	Standards for the temperatures of heated and cooled items, standards for the temperatures, pressures, flow rates, etc. of thermal media, and standards for the temperature and humidity of air conditioning.	Standards for insulation construction.	Standards for the recovery and utilization of waste heat	Standards for the adjustment of loads between multiple boilers and turbines, and standards for the minimum tolerated pressure in exhaust and back pressure turbines.	Control standards for the voltages, currents, power factors, load factors and demand factors of substations and distribution equipment.	Standards for voltages, currents, power factors and demand factors related to electric power application, electrical heating, illumination equipment, etc.
Implementation of instrumentation, records, etc.	Instrumentation and records, etc. for fuel supply quantities, exhaust gas temperatures, residual oxygen quantities in exhaust gases, etc.	Instrumentation and records, etc. for gaining an understanding of thermal movement through temperatures, pressures, flow rates, etc., and instrumentation and records, etc. for the temperature and humidity of air conditioning.	Implementation of thermal account analyses.	Instrumentation and recods, etc. for items related to understanding the status of waste heat, and investigation of effective methods for utilizing waste heat.	Instrumentation and records for the thermal efficiency of main boilers and turbines; Instrumentation and records for operation under minimum tolerated pressure.	Instrumentation and records for the values above.	Instrumentation and records for the values above. (Including the intensity of illumination.)
Implementation of maintenance and inspection.	Maintenance and inspection of combustion facilities.	Prevention of decreases in thermal conductivity performance, water quality control for boiler water, and maintenance and inspection of air conditioning facilities.	Prevention of leaking from damage in heat transfer media, maintenance of insulation sections, and maintenance and inspection of steam traps.	Removal of grime from the thermal transfer surfaces of waste heat recovery equipment, prevention of leaking of heat transfer media from equipment, etc.	Maintenance and inspection of boilers and turbines, maintenance and inspection of turbine blades, etc. during operation under minimum tolerance pressure.	Maintenance and inspection of substations and power distribution facilities.	Reduction of mechanical loss such as friction, prevention of fluid leaks in machines which handle fluids, and maintenance and inspection for other thermoelectric, electrolysis, and illumination facilities.
Improvement measures and equipment introduced for rationalization.	Adjustment of combustion loads, selection of appropriate burners, improvements in ventilation devices, installation of combustion control devices, and installation of heat accumulators.	Reviews of heat usage conditions and supply conditions, improvements in heat patterns, adjustment of loads, improvements in direct heating, multiple stage use of heat, introduction of equipment which have high thermal efficiency, introduction of continuous and combined processes, and the shortening and removal of processes.	Improvements in insulation, reducing the size of openings, installation of covering facilities for open type equipment, rationalization of piping routes, etc.	Preventing decreases in temperatures of waste heat during transfer processes, improvements in the heat transfer aspects of waste heat recovery devices, installation of recovery and utilization equipment to meet the uses of waste heat.	Modifications to turbines to reduce the minimum tolerance pressure. Utilization of usable surplus steam for power generation and sources of energy for work.	Improvements in power factors, such as the operation of transformers at appropriate loads, using transformers with the appropriate capacities, levelling of loads, and appropriate allocation of substation equipment, and improvements in three phase unbalance.	Preventing motors from running free, appropriate allocation of loads, and implementation of speed controls, etc. Installation of motors with the appropriate capacities, etc. Other improvements in equipment and the introduction of other equipment.