CHAPTER 6   AIR QUALITY MONITORING

6.1 Introduction

Three ambient air monitoring stations were placed each within about 15 km around the power plants at Tabriz and Esfahan. SO_2, NOx, wind direction and speed were monitored by automatic continuous analyzers. SPM and settled dust samples were collected at each station. Specification of the monitoring and sample collection equipment are shown as Items T-2, E-2, T-2-11, 12, E-2-11, 12, T-4, E-4 in Appendix 1-3.

As a supplemental method for automatic monitoring, passive samplers were set up at about 30 to 40 places within a 20 km radius of both power plants each season. Sampling devices are shown in T-3, E-3 in Appendix 1-5.

Major sampling methods and analytical principles are as in Table 6.1.1. Sampling methods for SPM, settled dust and passive samplers are detailed in Appendix 6-1.

Table 6.1.1 Sampling Methods and Analytical Principles

Item	Method (Frequency)	Analytical Principle
SO_2 (automatic)	Continuous	Ultra-Violet Fluorimeter
NOx (automatic)	Continuous	Chemi-luminescence
Wind Direction and Speed (automatic)	Continuous	Propeller
SPM	Low volume sampler (twice / month)	Weight and atomic absorption
Settled Dust	Plastic bottle (once / month)	Weight and atomic absorption
SO_2 and NO_2	Passive filter paper (once / season)	TEA (Ion chromatography)
NOx	Passive filter paper (once / season)	TEA-PTIO (absorptiometry)

Chemical analysis methods of samples of SPM, settled dust and passive samplers, their results and evaluation are described in Chapter 9.   Surface meteorology was observed at Tabriz and Esfahan power plants. Wind direction and speed data along with surface meteorology data are described in Chapter 5.

6.2 Air Quality Standards

The Second Five Year Plan (#51) has stated that WHO guidelines are targeted as air quality in Tabriz and Esfahan. Table 6.2.1 lists Iranian air quality standards of particulates, SO_2 and NO_2 based on WHO guidelines, which are converted to ppm from $\mu g/m^3$. Evaluation of data collected and analyzed in this report is carried out based on the primary criteria in Table 6.2.1.

Table 6.2.1   Air Quality Standards in Iran (# 90)

Pollutants	Averaging Time	Primary Criteria [2]		Secondary Criteria [3]	
		$\mu g/m^3$	ppm [4]	$\mu g/m^3$	ppm [4]
SO$_2$	Annual	80	0.03	60	0.02
	24 hours [1]	365	0.14	260	0.1
	3 hours [1]	-	-	1,300	0.5
NO$_2$	Annual	100	0.05	100	0.05
SPM	Annual	75	-	60	-
	24 hours [1]	260	-	150	-

Note: *1) not to be exceeded for more than one day per year

*2) Criteria required for protecting the health

*3) Criteria requiredfor protecting social welfare

*4) assuming the standards at 20℃ or 25℃

6.3   Automatic Air Monitoring

6.3.1   Results

Names of air monitoring stations and their distance from the power plants are listed in Table 6.3.1. The positions are illustrated in Fig. 1.2.1 and 1.2.2.

Table 6.3.1   Distance and Direction of Air Monitoring Stations from Power Plant

Stations in Tabriz Area		Stations in Esfahan Area	
Baranloo	about 4km West	Golshahr	about 13km West
Mayan Pump	about 8km North	Kaveh	about 15km Northeast
Qara Malek	about 16km Northeast	Shariati	about 9km East

Automatic air monitoring was started in June, 1998. After completion of adjustment, tuning and calibration of the JICA Equipment at each monitoring station, technology transfer was implemented. Manual calibration using standard gases was selected among other calibration methods for training in order to give the calibration procedure completely. Data has to be transferred from the analyzers to floppy disks through computer once a week at each station and those disks are sent to MOE once a month. The flow of data processing and maintenance sheets is shown in Appendix 6-2.

Monitoring results from June, 1998 to May, 1999 in Tabriz and Esfahan were given in the

Computer Primary Outputs and summarized here in Tables 6.3.2 and 6.3.3, and Figure 6.3.1 and 6.3.2. An AC/DC converter of NOx analyzer at Kaveh in Esfahan was found to have been damaged, as a result of a local agent's investigation in September 1998. The converter was not delivered in time for the latter half of data logging, because it took too much time to clear the customs.

Table 6.3.2   Results of Air Monitoring from June, 1998 to May, 1999 (Tabriz)

	SO$_2$(ppm)			NO$_2$ (ppm)	
	Annual Mean	Daily Mean (Max.)	Hourly Mean (Max.)	Annual Mean	Hourly Mean (Max.)
Baranloo	0.005	0.023	0.140	0.008	0.062
Mayan Pump	0.003	0.037	0.230	0.007	0.068
Qara Malek	0.012	0.051	0.194	0.020	0.111

Table 6.3.3   Results of Air Monitoring from June, 1998 to May, 1999 (Esfahan)

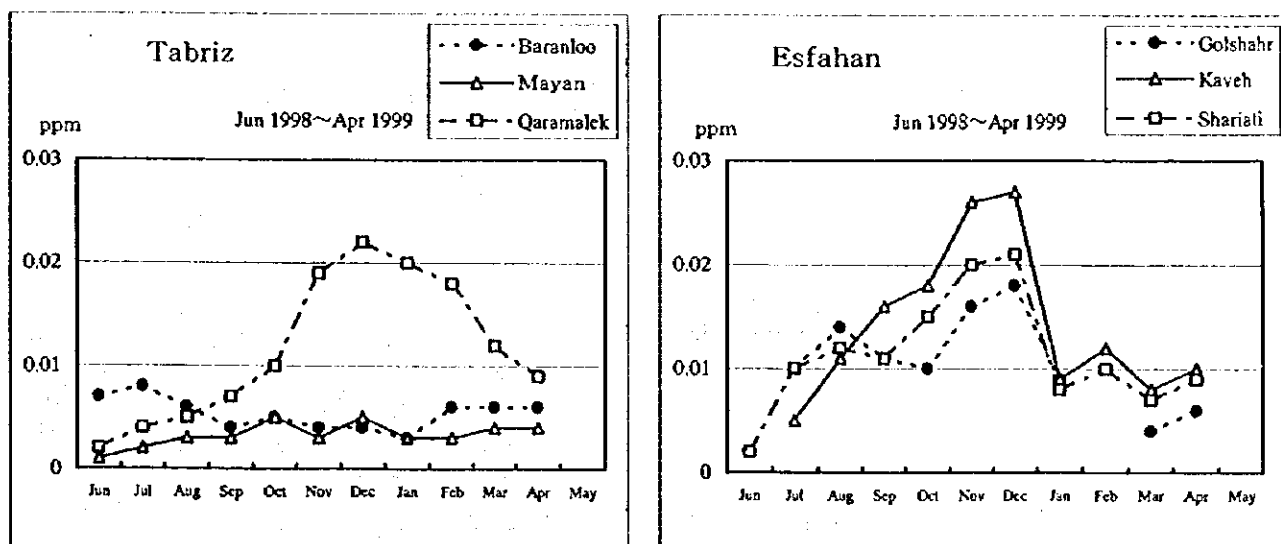|	SO$_2$(ppm)			NO$_2$ (ppm)	
	Annual Mean	Daily Mean (Max.)	Hourly Mean (Max.)	Annual Mean	Hourly Mean (Max.)
Golshahr	0.011	0.032	0.129	0.024	0.198
Kaveh	0.014	0.058	0.121	0.019*	0.073*
Shariati	0.012	0.047	0.221	0.038	0.266

Note : * Data logged from June to September for four months
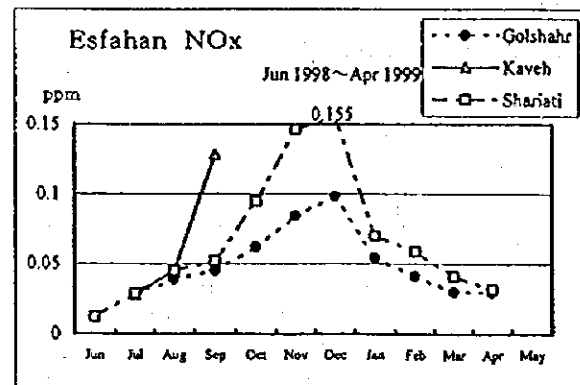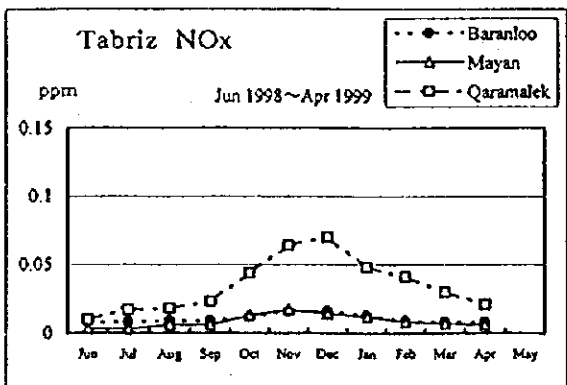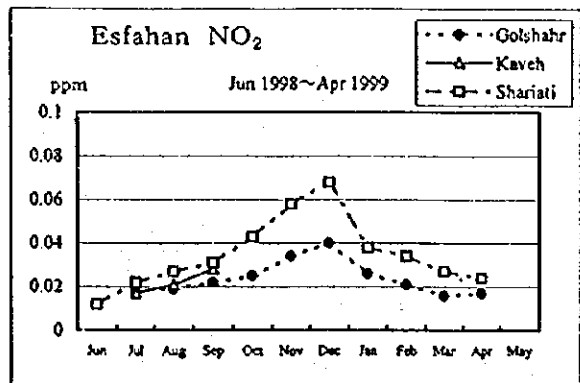

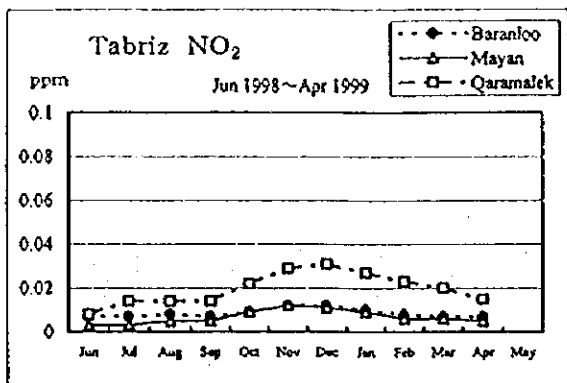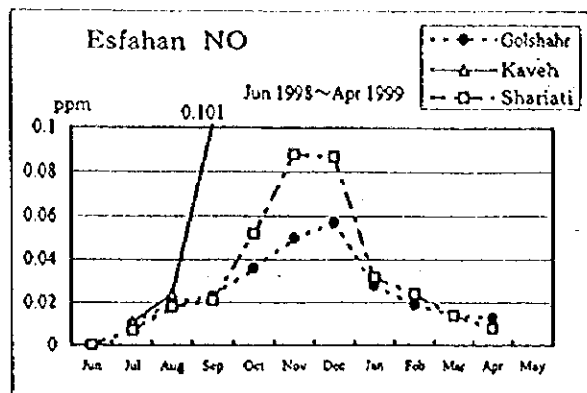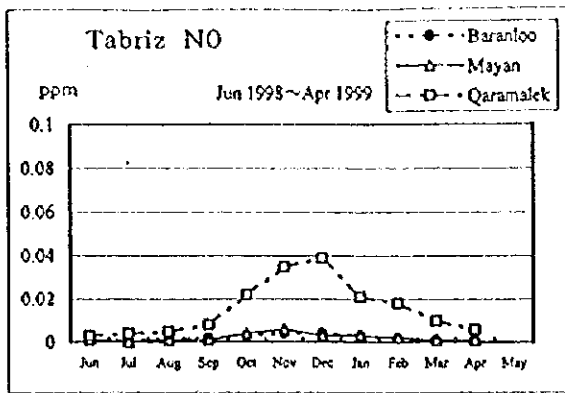Fig.6.3.1 Monthly Changes in SO$_2$

Fig.6.3.2 Monthly Changes in NOx

SO$_2$ concentrations at all stations in both areas are low in comparison with the Air Quality Standards of annual and daily averages. NO$_2$ concentrations also are low from the Standards, except at Shariati in Esfahan which is around 75% of the Standard.

6.3.2 Evaluation

As the results, SO$_2$ concentrations in Esfahan and Tabriz are much below the Iranian Standards value for annual mean, 0.03 ppm, and the Iranian Standards value for daily mean, 0.14 ppm. NO$_2$ concentrations in Esfahan and Tabriz are also less than the Iranian Standards for annual mean , 0.05 ppm.

SO$_2$ and NOx Concentration Frequency Charts are shown in **Fig. 6.3.3** to **Fig. 6.3.4**. Highest frequency of SO$_2$ concentration is in the lowest rank of 0~0.005ppm and the frequency is less in higher concentration. This tendency is predominant in Tabriz and indicates low concentration of SO$_2$ there. In Tabriz, the frequency of NOx concentration is in the highest in 0 ~0.005ppm rank and lower at higher concentration ranks. However, in Esfahan, the highest frequency is in 0.010~0.015ppm or 0.005~0.010ppm showing a sloped curve.

These indicate exhaust gases from automobiles may be regarded as one of the reasons of high NOx concentrations in Esfahan because three monitoring stations were placed near arterial roads, which were allegedly affected by the exhaust gas.

6.4   SPM, Settled Dust and Bag Samplings

6.4.1 SPM

SPM monitoring was carried out from January to December, 1998 on the roofs of air monitoring stations or in the neighborhood of the stations.

The SPM monitoring results are summarized in **Table 6.4.1** and **Fig. 6.4.1** to **6.4.2**. The original data is given together with chemical data in **Appendix 6-3**. Sampling days varied every month from 9 to 31 days.
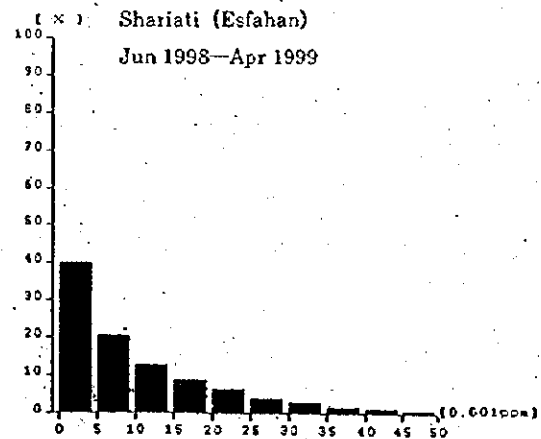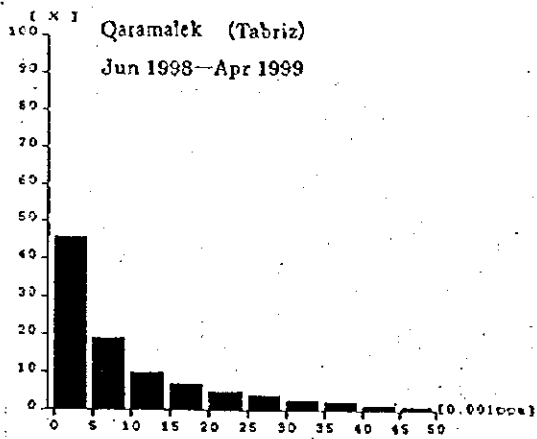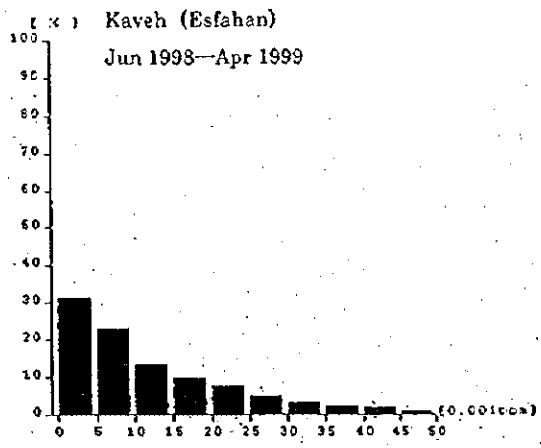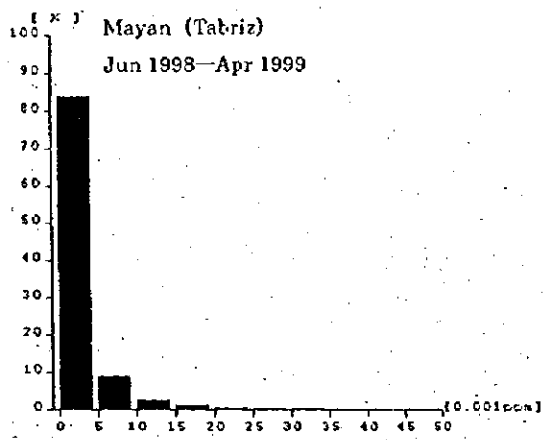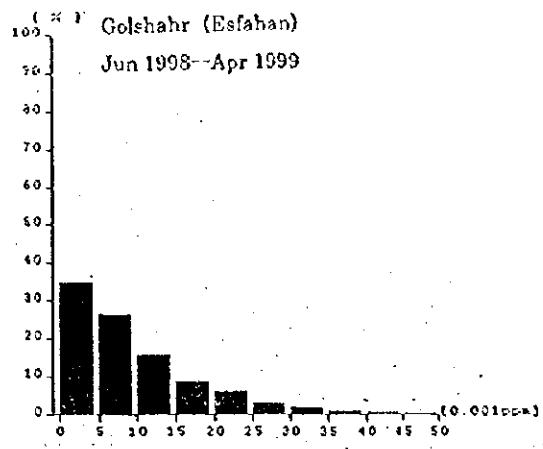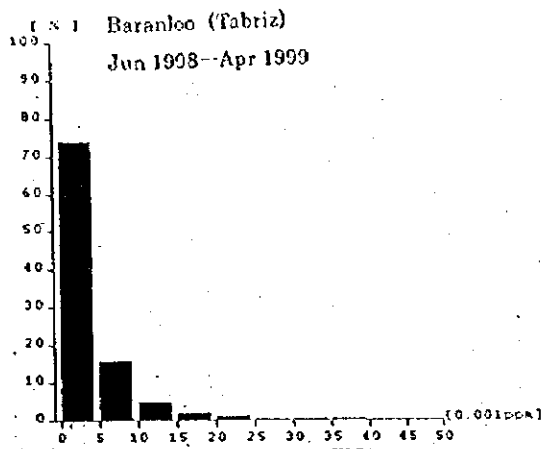
Fig. 6.3.3　Frequency by SO₂ Concentration Class
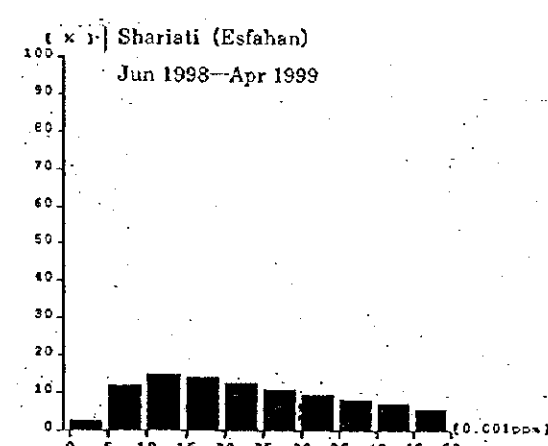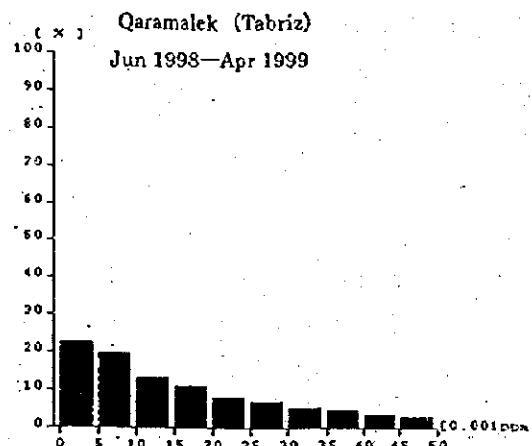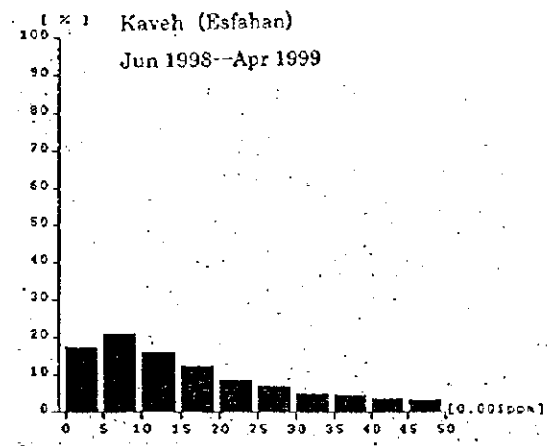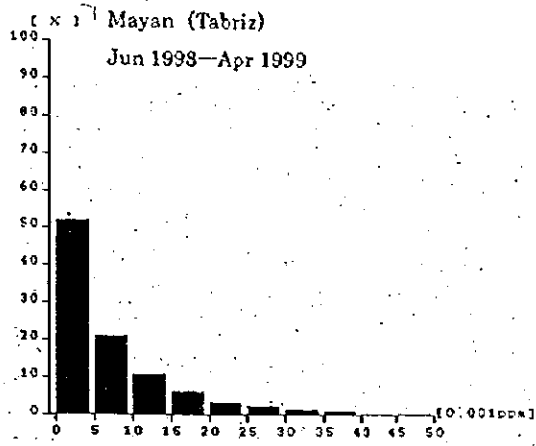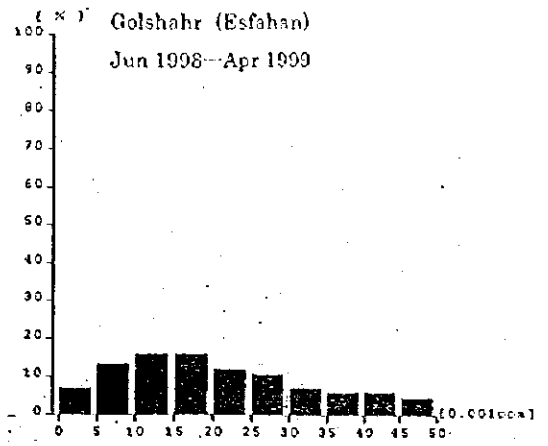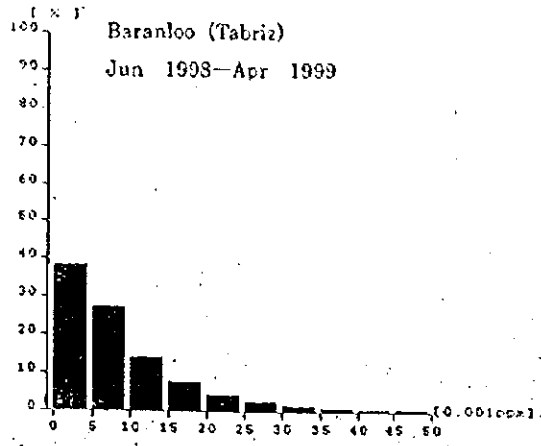
Fig. 6.3.4 Frequency by NOx Concentration Class

Table 6.4.1 Results of SPM Monitoring

Location		SPM (μg/m³)	Annual Mean (μg/m³)
Tabriz	Baranloo	29.4~ 97.7	58.8
	Mayan Pump	22.0~ 71.7	41.2
	Qara Malek	23.7~ 72.6	44.4
Esfahan	Golshahr	27.7~156.9	69.1
	Kaveh	22.0~150.0	65.8
	Shariati	17.3~128.8	69.6
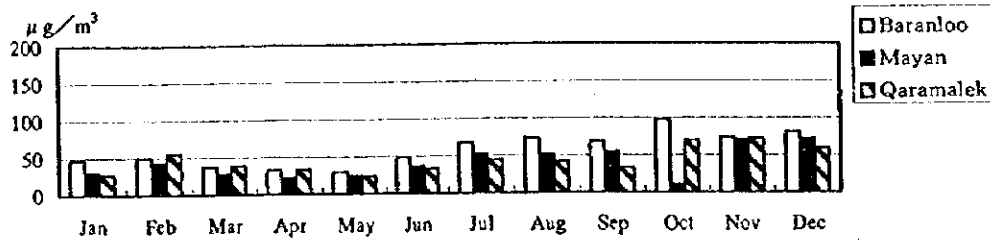
Fig. 6.4.1 Monthly Changes in SPM (Tabriz)
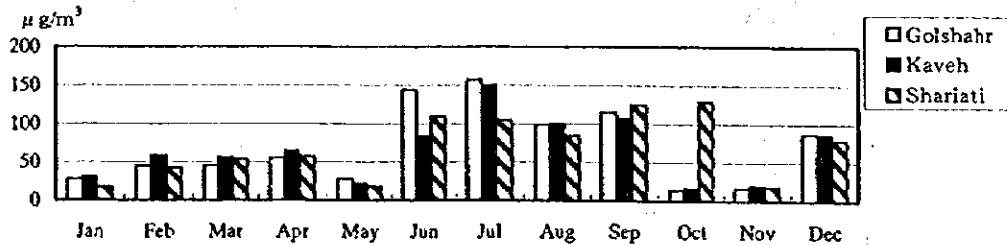
Fig. 6.4.2 Monthly Changes in SPM (Esfahan)

SPM loading is low in the range of 20~50 μg/m³ in February to June and a little higher in the range of 40~100 μg/m³ in July to December in Tabriz. In Esfahan, it is low at 20~60 μg/m³ in January to May and November and is higher at 80~160 μg/m³ in June to September.

The annual average SPM loadings at all six stations are lower than 75 μg/m³, the Iranian Standard given in Table 6.2.2. The low volume samplers is unable to generate accurated daily average value. Hower, the highest monthly average of 156.9 μg/m³ in Esfahan is possible to have higher daily average values than 260μg/m³ given in the Iranian Standard. It is recommended to check the daily average value using an automated continuous SPM analyzer given in Appendix 6-4 as an example of the kind.

6.4.2 Settled Dust

Settled dust monitoring was carried out from February to December, 1998 on the roofs of air monitoring stations or in the neighborhood of the stations.

The settled dust monitoring results are summarized in **Fig. 6.4.3** to **Fig. 6.4.4**. The original data is given together with chemical data in **Appendix 6-5**.

In general, Esfahan has less settled dust with an annual average of 2.3 tons to 3.6 tons/km^2/month than that of Tabriz with an average of 5.3 tons to 5.9 tons/km^2/month.

Table 6.4.2   Results of Settled Dust Monitoring from February to December 1998

Location		Monthly Range	Annual Average
Tabriz	Baranloo	0.764 ～ 8.815	5.4
	Mayan Pump	0.877 ～ 9.987	5.9
	Qara Malek	2.860 ～ 8.831	5.3
Esfahan	Golshahr	0.670 ～ 7.245	3.6
	Kaveh	0.571 ～ 8.372	3.3
	Shariati	0.851 ～ 6.324	2.7

unit : ton/km^2 /month
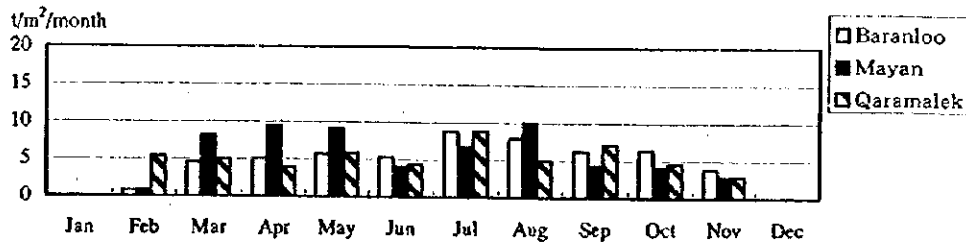
Fig. 6.4.3   Monthly Changes in Settled Dust (Tabriz)
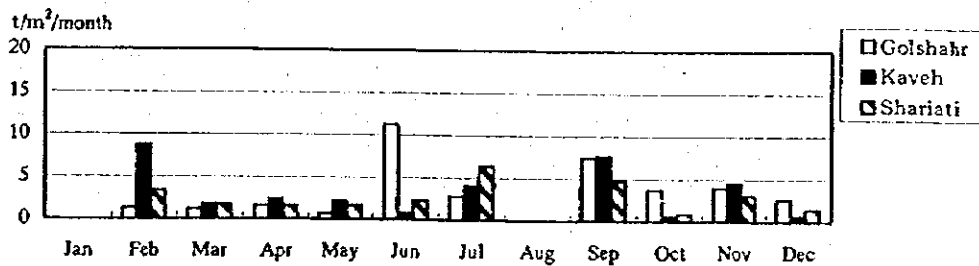
Fig. 6.4.4   Monthly Changes in Settled Dust (Esfahan)

6.4.3 Air Monitoring At Qa-e-Mich

Bag sampling monitoring, air is inhaled with a pump and is introduced to a Teflon Bag, was carried out at Qa-e-Mieh, a small community, which was allegedly affected by air pollution from the power plant. The township is located on the other side of the slope of the hill behind the Esfahan plant.

Samples were taken on every hour for 24 hours and analyzed using an automated analyzers at the Shariati station. The results of monitoring together with wind direction and wind speed, temperature are shown in **Appendix 6-6** and are summarized in **Table 6.4.3** and in **Fig. 6.4.5** and **6.4.6**.

Table 6.4.3   Results of Air Monitoring at Qa-e-Mie

Date measured	SO$_2$ (ppm)	NOx (ppm)
from June 30 to July 1, 1998	0.0001 ~ 0.0006	0.0018 ~ 0.0178
from Jan.25 to Jan.26, 1999	0.0011 ~ 0.0058	0.0154 ~ 0.0661

When the summer monitoring was carried out, apparently wind blew in the opposite direction. In winter, the concentrations were higher than those of summer. However, as in **Fig. 6.4.6** of the wind rose in January, wind direction was again in the opposite. The JICA Team recommends to monitor the situation in Qa-e-Mieh for a long period, possibly for a year, using automated continuous analyzers and wind meters.
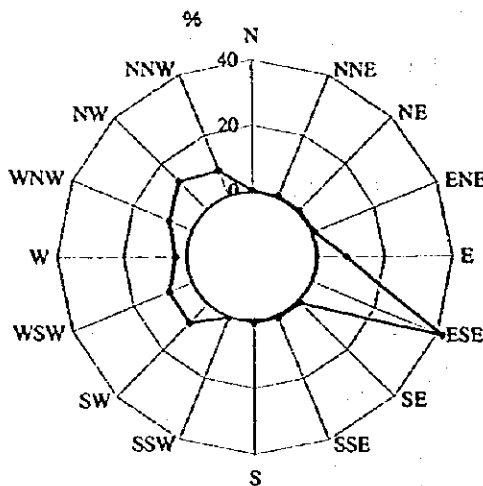
Fig.6.4.5   Wind Rose at PowerPlant
Jun 30 1998 15:00~Jul 1 14:00
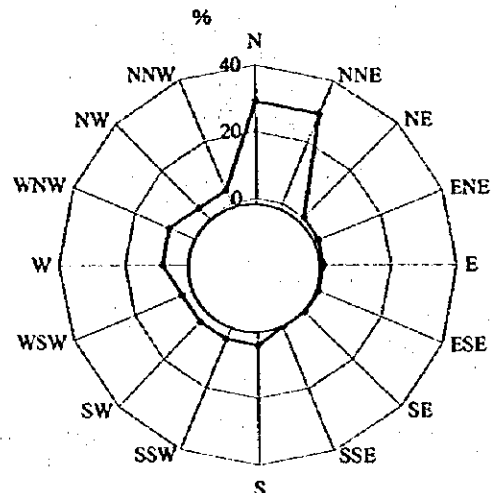
Fig.6.4.6 Wind Rose at Power Plant
Jan 25 1999 15:00~Jan 26 14:00

CHAPTER 7   STACK GAS MONITORING

7.1   Monitoring

7.1.1   Methods

The JICA Team examined existing boilers of Tabriz and Esfahan power plants for stack gas monitoring in the First Field Work. The targeted boilers were narrowed down to No.1 and 2 boilers of Tabriz power plant, and No. 3, 4 and 5 boilers of Esfahan power plant in this Study. No. 1 and 2 boilers of Esfahan power plant were excluded from the target because of their small capacity and no appropriate space for sampling. Sampling nozzle positions and sizes, specifications of monitoring stages, and requirement of electric power supplies, etc. were decided at each boiler, as listed in Appendices 7-1 and 7-2.

Monitoring apparatuses listed in Appendix 1-3, a series of Items T-1 was employed to carry out monitoring for emissions of SO_2, NOx, O_2, soot, and water, and stack gas velocity and temperature. The set of equipment was moved from one boiler to the other, from Tabriz to Esfahan or vice versa for the monitoring. Their principles of the analyses are summarized in Table 7.1.1. The monitoring was carried out on the condition that the operating load of the boiler was kept at constant as much as possible during the monitoring. Tabriz No. 2 Unit was monitored only once in winter 1999, because of its prolonged maintenance and repair work.

Table 7.1.1   Principles of Stack Gas Monitoring Methods

Analyzer		Method	Standard Applied
SO_2		Infrared absorption	JIS-B7981-84
NOx - O_2		Chemiluminescence	JIS-B7982-88
		Zirconia ion conductivity	JIS-B7983-94
Soot	Dust sampler	Cylinder filter-paper method I type and Suction flow rate for equal velocity aspiration method	JIS-Z8808-92
	Concentration of soot	Weight method	
	Water content	$CaCl_2$ absorption	
	Velocity of gas flow	Pitot tube	
	Gas temperature	Thermocouple	

7.1.2 Monitoring and Technology Transfer

Appendix 7-3 was distributed among people in charge, before commencement of the monitoring, to give complete idea of monitoring procedures. The time required for one full

scale monitoring was reduced from 10 hours to 5 hours approximately by the end of the Study. It is believed that the Iranian Counterparts can carry out the monitoring by themselves without any problem from now on.

7.2 Monitoring Results and Evaluations

7.2.1 General

Following four tables are prepared for the basis of the data evaluation: a) Table 7.2.1 DOE's Proposed Emission Standards (#90), b) Table 7.2.2 Emissions from Similar Boilers (#95-96), c) Table 7.2.3 Design Specification (#28 and others), and d) Table 7.2.4 Design Heat Input Rate of Tabriz Units 1 and 2.

Table 7.2.1   Emission Standards Proposed by DOE (#90)

Pollutants	Emission Standards
SO_2	800 ppm
NOx	350 ppm
CO	150 mg/m^3
PM	150 mg/m^3
Smoke	20 %

Table 7.2.2   Emission from Similar Boilers

Fuel Oil Combustion (#95)		Natural Gas Combustion (#96)	
Pollutant	Emissions / Fuel Oil	Pollutant	Emissions / Natural Gas
NOx	5.64 kg/m^3	NOx	4,480 kg/10^{6}m^3
PM	(9.19(S)+3.22)×0.12 kg/m^3	PM	121.6 kg/10^{6}m^3

Note: (S) - sulfur in fuel oil, % by weight

Table 7.2.3   Design Specification at Rated Capacity (Table 3.2.1)

Power Plant	Unit	Capacity (MW)	Fuel Oil (t/h)	Stack Gas*[1] (m^{3}N/hr)
Tabriz	1	368	65	950,000
	2	368	65	950,000
	3	120	30	440,000
Esfahan	4	320	71	1,030,000
	5	320	71	1,030,000

Note 1): Assumed by the JICA Team from the general engineering knowledge as 14.6 m^{3}N/kg of fuel oil. The JICA Preparatory Team reported in March 1996 that it was 12.6 m^{3}N/kg at Neka Plant.

Table 7.2.4 Design Heat Input Rate of Tabriz Units 1 and 2 (#28)

Capacity	368MW 100%	276 MW 75%	184 MW 50%	92 MW 25%
Heat Input Rate (kcal/kwh)	1,852	1,850	1,908	2,232

The results of the monitoring are given in Appendix 7-4-1 and 7-4-2. And individual results of each monitoring are detailed in Appendices 7-4-3~-23. The summary of the results is tabulated individually by topics in Tables 7.2.5~14, which have common notations of a) O_2 contents in stack gas to be 6 %, b) Assumed 10 % of water contents in stack gas of Tabriz No. 2, c) Disregarded abnormal results (indicated in Appendix 7-4-), and d) Gave in the range of the data from plural times of monitoring. The reason of the standardization of oxygen contents in the stack gases is to eliminate dilution effects by excess or leaked air.

7.2.2 Generation Capacity and Fuel Requirment

Table 7.2.5 gives fuel consumptions and heat rates with generation capacities when the stack gases have been monitored. The heat rate is calculated based on heat of combustion to be 10,000kcal/kg of fuel oil and 8,680kcal/m^3 of natural gas.

Table 7.2.5 Heat Input Rate vs. Generation Capacity

Power Plant	Units	Fuel Input t/hr	Fuel	Capacity MW	Calculated Heat Input per Capacity, kcal/kwh
Tabriz	1	65		290	2240
		79	Fuel Oil	345	2290
	2	73		345	2120
Esfahan	3	19.2	Fuel Oil	74	2600
		20		77	2600
		10.8+(9.4)	Fuel Oil &	75	2690
		11 +(9.5)	Natural Gas	75	2730
		19.2+(14.8)		120	2830
	4	71		320	2220
		70	Fuel Oil	320	2190
		36		160	2250
		23 +(17.4)	Fuel Oil &	160	2530
		3.2+(28.4)	Natural Gas	160	1980
	5	39	Fuel Oil	170	2290
		3 +(39.1)	Fuel Oil &	220	1910
		4 +(40.8)	Natural Gas	220	2040

Note: Fuel input given in ( ) is an oil rate equivalent to natural gas amount burnt.

Heat input rates are less at the larger boilers than a smaller boiler. They are almost constant

regardless of the generation capacity at the one specific boiler such as Esfahan No. 4, by burning fuel oil only. Higher natural gas ratio results less heat input rates at Esfahan No. 4 and, on the contrary, higher heat input rate at Esfahan No. 3, when oil and gas are burnt simultaneously. Reason on this different indication is unknown.

The actual heat input rates at Tabriz are much higher than the designed rate in Table 7.2.4. The rates at 345MW are nearly equal to the designed rate of 92 MW (25 % generation capacity). It seems Tabriz is operated in lower efficiency, or panel indications of the fuel rates are not accurate.

7.2 3   SO₂

Table 7.2.6 shows the results of SO₂ monitoring in stack gases. All boilers except Tabriz No. 2 do not satisfy the standard value of 800 ppm proposed by DOE (Table 7.2.1), when burning the oil only.

Table 7.2.6   SO₂ Monitoring Results

Power Plant	Unit	Fuel	SO₂		
			Concentration (ppm)	Emission (kg/hr)	Emissions per Output (kg/MWh)
Tabriz	1	Fuel Oil	1180~1370	1930~4530	6.7~13.1
	2	Fuel Oil	618	2000	5.8
Esfahan	3	Fuel Oil	1300~1390	944~1280	12.3~17.3
		Oil & Gas	625~664	362~794	4.8~6.6
	4	Fuel Oil	1350~1420	2580~2820	8.1~17.6
		Oil & Gas	202~650	315~872	2.0~5.5
	5	Fuel Oil	1390	2540	14.9
		Oil & Gas	85~93	77	0.4

Amounts of SO₂ emission should be proportional to sulfur contents in the fuel. If the fuel input rates per kwh are nearly equal and the same kind of fuel is used, amounts of SO₂ emission per kwh should be equal in each case. There must be wide fluctuation of sulfur contents in fuel oils, because there are about twice of difference in the results of Tabriz No. 1 and 2 and also there are no relevancy in SO₂ concentration and emission rates with fuel consumptions at the No. 1 Unit.

There are apparent and inherent differences of SO₂ concentrations in Esfahan between fuel oil exclusive and simultaneous burning of fuel oil and natural gas. Esfahan is probably burning different kinds of fuel oils, because its No. 4 Unit has wide range of SO₂ concentrations.

7.2.4 NOx

From the results of NOx monitoring given in Table 7.2.7, Tabriz Unit No. 1 only has data above the DOE proposed standard of 350 ppm. The monitoring seems acceptable since the emissions per generation output are within narrow ranges, except Esfahan Unit No. 4. As in Appendix 7-4-2, Esfahan Unit No. 4 indicated two data above the proposed standard. The JICA Team decided these data to be out of range because of the reported mal-functioning of the NOx analyzer.

Table 7.2.7 Results of NOx Monitoring

Power Plant	Unit	Fuel	NOx		
			Concentration (ppm)	Emission (kg/hr)	Emission per Output (kg/MWh)
Tabriz	1	Fuel Oil	385~486	269~417	0.9~1.2
	2	Fuel Oil	—	—	—
Esfahan	3	Fuel Oil	163~215	60~70	0.8~0.9
		Oil & Gas	132~298	67~167	0.9~1.4
	4	Fuel Oil	240~296	231~235	0.7~1.5
		Oil & Gas	—	—	—
	5	Fuel Oil	180	154	0.9
		Oil & Gas	78~112	44	0.2

There are two kinds of NOx: fuel NOx which is generated from flamable nitrogen compounds in fuel and thermal NOx which is from nitrogen in air. Generally, NOx generation is higher by solid fuel combustion and lower by gas combustion. Liquid fuel is in the middle. As there is almost no flamable nitrogen compound in the gas fuel, there is no generation of thermal NOx by gas combustion. Also as gas is easy to mix with air before combustion and the combustion time is shorter than other fuel types, NOx generation by gas burning is less than those by other types of fuel burning. As for reference, thermal NOx is 100% for gas burning, 30 to 40 % for residual fuel oil and 10 to 20% for coal, of the total NOx generated.

Table 7.2.8 NOx Emission in Comparison with Data of Similar Boilers

Power Plant	Unit	Fuel Oil Burnt (t/hr)	NOx Emission (kg/hr)	Referred Data (kg/hr) (Table 7.2.2)
Tabriz	1	65~79	269~417	386~469
	2	73	—	434
Esfahan	3	19.2~20	60~70	114~119
	4	36~71	231~235	214~422
	5	39	154	232

Table 7.2.8 is composed to compare the monitoring results of the fuel oil combustion with those of similar boilers given in Table 7.2.2. The results are close to the referred data.

Natural gas 1 m^3 listed in Table 3.2.4 will generate 9.54 m^3N of flue gas after combustion at the air ratio of 1.3 with remaining O_2 of 6.3%. Table 7.2.2 indicated 0.00448 kg of NOx is generated in large boiler operation.

$$0.00448 \times (22.4/46) \times 10^6 / 9.54 = 230 \text{ ppm}$$

Calculation shows 230 ppm of NOx is contained in average by natural gas combustion. By adjustment of O_2 to 6%, it is 234 ppm and is under the DOE's proposed emission standard.

After conversion of fuel oil to natural gas, it is easier to keep excess air ratio in low, and to control combustion. It will not generate more than the DOE proposed standards of 350 ppm.

7.2.5 Soot

Table 7.2.9 is a compilation of soot monitored results. Many data do not satisfy the standard value (150 mg/m^3) proposed by DOE when burning fuel oil only. However, after conversion of the oil to natural gas, this would not be a problem anymore.

Table 7.2.9 Results of Soot Monitoring

Power Plant	Unit	Fuel	Soot		
			Concentration (mg/m³N)	Emission (kg/hr)	Emission per Output (kg/MWh)
Tabriz	1	Fuel Oil	90~210	54~258	0.2~0.7
	2**	Fuel Oil	—	—	—
Esfahan	3	Fuel Oil	130~260	33.9~84.5	0.44~1.14
		Oil & Gas	120~470	48.4~50.9	0.42~0.65
	4	Fuel Oil	90~740	66.2~467	0.41~1.46
		Oil & Gas	40~90	20.8~41.3	0.13~0.26
	5	Fuel Oil	140	87.0	0.51
		Oil & Gas	50~60	14.8	0.07

The results are compared in Table 7.2.10 with the referred data of similar boilers. The results of the Study are under the referred data except those from Unit No. 4 of Esfahan at burning exclusively fuel oil.

Table 7.2.10   Soot Results in Comparison with Those of Similar Boilers

Power Plant	Unit	Fuel Oil Burnt (t/hr)	Natural Gas Burnt (m³/hr)	Soot Emission (kg/hr)	Referred Data (Table 7.2.2) (kg/hr)
Tabriz	1	65~79	–	54~258	276~335
	2	73	--	–	310
Esfahan	3	19.2~20	–	33.9~84.5	81.4~84.8
		11~19.2	11000~17100	48.4~50.9	47.9~83.5
	4	36~71	--	66.2~467	153~301
		3.2~23	20000~32700	20.8~41.3	17.5~99.9
	5	39	–	87.0	165
		3~4	45000~47000	14.8	18.1~22.6

7.2.6 Residual Oxygen in Stack Gas

Table **7.2.11** shows monitored results of oxygen concentration in stack gases. The concentration was in the range of 11 to 13 % in the data of Tabriz Unit No. 1. However, it was reportedly reduced drastically to 3.5% after maintenance of the air heater. In Esfahan, it was rather consistently in the range of 7 to 11 % when burning oil. It was in the wide range of 9 to 17 % when oil and gas were burnt simultaneously. It is supposed to have difficulty to control combustion in those occassions. Both plant managements were aware of air leakage from the air heaters. Air can be suched into the flue system not only from an air blower but also from vacuum draft caused by hot flue gas buoyancy in the stack.

Table 7.2.11   Residual Oxygen in Stack Gases

Power Plant	Unit	Fuel	Residual O₂ Concentration %
Tabriz	1	Fuel Oil	11.6~13.5 (3.5 after maintenance)
	2	Fuel Oil	– (4.6 after maintenance)
Esfahan	3	Fuel Oil	8.5~11.0
		Oil & Gas	9.3~16.9
	4	Fuel Oil	6.8~12.7
		Oil & Gas	9.2~10.9
	5	Fuel Oil	8.1
		Oil & Gas	14.8~15.5

Table **7.2.12** was composed to tabulate calculated results of combustion heat, wet stack gas rate, and residual oxygen concentration by assuming fuel oil elemental composition and giving stoichiometry combustion air ratio. The elemental composition were carbon: 85%, hydrogen: 11%, sulfur: 3%, and nitrogen: 1 % by weight. The calculation is partly verified by that the combustion heat of 10,161 kcal/kg (=18,290 Btu/lb) is almost the same with the one of the fuel

oil used in Tabriz given in Table 3.2.2.

Table 7.2.12 Combustion Calculation by Assumed Fuel Oil Composition

Combustion Heat (kcal/kg fuel)	10,161				
Air Ratio	1.1	1.2	1.3	1.4	1.5
Wet Stack Gas (m³N/kg fuel)	11.0	12.1	14.4	15.5	16.5
Residual Oxygen (%)	2.0	3.7	5.1	6.3	7.3

Note) Assumed composition of fuel oil - C: 85%, H: 11%, S: 3%, and N: 1 % by volume

Esfahan reported that the oxygen concentration was in the range of 2 to 3 % by Orsat analyses in flue gas before an air heater in the end of January 1999. It seems to be in operation in good control. However, the operation should be under the air ratio of 1.15 to have residual oxygen below 3 %. It is unusual to operate fuel oil burning boiler under such low air ratio. The JICA Team suggests to check and maintain Orsat analyzers carefully.

Another verification of the combustion calculation in Table 7.2.12 is that the stack gas volume per kg of fuel at air ratio 1.3 is similar to those given in Table 7.2.3, the design specification. The 1.3 is the reasonable air ratio to burn residual fuel oil.

7.2.7   Stack Gas Flow Rate

Monitored wet stack gas flow rates are given in Table 7.2.13. It seems from the wide differences of the stack gas rates at larger boilers by fuel oil only burning that there are difficulty of combustion control or leakage of air to the system.

Table 7.2.13   Monitored Wet Stack Gas Flow Rate

Power Plant	Unit	Fuel	Capacity (MW)	Wet Stack Gas (10⁶m³N/hr)	Wet Stack Gas per Output (m³N/MWh)
Tabriz	1	Fuel Oil	290~350	1.13~1.27	3230~4000
	2	Fuel Oil	345	1.15	3330
Esfahan	3	Fuel Oil	74~77	0.37~0.42	4930~5540
		Oil & Gas	75~120	0.40~0.60	5000~5330
	4	Fuel Oil	160~320	0.84~1.26	3940~5390
		Oil & Gas	160	0.77~0.80	4810~5000
	5	Fuel Oil	170	0.82	4820
		Oil & Gas	220	0.93	4230

As in Table 7.2.4, the designed heat input rate at 50% capacity is only 3% more than that at 100% capacity. Therefore, there must not be much difference in the stack gas rate per MWh within 50 to 100 % capacity range. Table 7.2.14 is to compare the actual stack gas rates with those given in Table 7.2.3, the assumed designed value of the stack gas rate divided by the rated output. The actual rates are 22 to 67 % higher than the assumed designed rates. As the differences with the assumed designed values become larger at smaller generation capacities, the air ratio must be far larger than 1.3, or the combustion control is probably unstable, at smaller capacities.

Table 7.2.14   Design vs. Monitored Wet Stack Gas per Output (Fuel Oil Burning)

Power Plant	Unit	Capacity MW		Wet Stack Gas per Output (m^3N/MWh)		
		Design	Monitored	Assumed Design(A)	Monitored(B)	(B/A) Ratio
Tabriz	1	368	290 - 350	2580	3230~4000	1.25~1.55
	2	368	345	2580	3330	1.29
Esfahan	3	120	74 - 77	3670	4930~5540	1.34~1.51
	4	320	160 - 320	3220	3940~5390	1.22~1.67
	5	320	170	3220	4820	1.50

7.2.8   Conclusion

Following are the conclusion obtained from the stack gas monitoring of both power plants:
①Oxygen contents in the stack gases are far higher than those of fuel oil burning ordinary boilers. Both power plants understood there were air leakage from air heaters.
②Wet stack gas rates are 22~67 % higher than the assumed designed rates.
③There were less relevancy in the relations of output capacities vs. fuel consumptions, output capacities vs. stack gas rates, and fuel consumptions vs. SO_2 emissions.
④There must be a wide variation of sulfur contents in fuel, or must be inaccuracy of fuel oil flow meters.
⑤The stack gases have higher NOx concentrations and narrower the concentration ranges at oil burning than at oil and gas simultaneous burning.
⑥It seems that operators are experiencing difficulty in keeping the specified generating capacity in the oil and gas simultaneous burning method.
⑦Oxygen monitoring by an Orsat Analyzer at field is questionable, and also indications of oxygen meters on the control panel seem not working correctly.

The power plant operation was far from environmental consideration and energy saving at both power plants. It seemed that the plants were operated only to generate power as required or specified.

CHAPTER 8   EFFECTS OF POWER PLANTS ON AIR QUALITIES

8.1 Outline of Impact Assessment from Stack Gas

The impacts of the stack gas emitted from Tabriz and Esfahan plants to the surroundings were estimated with a dispersion simulation model. The model, based on Plume and Puff formulae, simulated annual averages, daily averages, and hourly values of SO_2, NO_2, and SPM. The conversion from NO_x to NO_2 were conducted with a exponential model. The effects of buildings around the stacks and topography under special meteorological conditions were also estimated.

Input data on pollutant emissions and power generation of each plant were based on the results of **Chapters 3 and 7**. Data of other emission sources in the target areas, such as large factories, small and medium factories and establishments, households and vehicles, were also obtained for fuel consumption, traffic volumes and so on.

The necessary meteorological inputs to the simulation model are wind direction, wind speed, atmospheric stability, which were based on the winds, solar and net radiation described in **Chapter 5**. The upper layer observation results were analyzed, and correction factors for estimating wind speeds at the stack heights, lid heights and potential temperature gradients were obtained and used by the simulation model. Diffusion parameters of atmospheric stability classes were calibrated based on the comparisons of the measured pollutant concentrations and the calculated values with all emission sources in the target areas.

8.1.1 Emission Source Model

(1) Target Power Plants

Emission rates of pollutants such as SO_x, NO_x, and soot (PM), stack gas volume, and gas temperature were applied for the simulation. If one of the parameters among pollutant concentrations, gas volumes, fuel consumption, and operation load at the measurement is not obtained or regarded abnormal (Chapter 7), the data set of the measurement at the date were discarded. The averages of the parameters were obtained from the multiple measurements for the same facility, and used as unit parameters per fuel consumption at the measurement (Table 8.1.1 and Table 8.1.2)

Monthly fuel consumption, power generation data during the target period, and hourly pattern of the generation were obtained from Tabriz and Esfahan power plants

for a period of one year from June of 1998 through May of 1999 (Appendix 8-1). Monthly pollutant emissions and stack gas volumes were obtained by multiplying unit pollutant emission and unit gas volume by the ratio of the monthly fuel consumption and the fuel consumption at the stack gas monitoring. After the monthly amounts were converted to the daily amounts, they were divided into hourly values of each facility unit with the weights of hourly generation pattern and each unit capacity.

Fuel oil and natural gas were sometimes burned simultaneously at Esfahan power plant. The fuel oil consumption under this mixture condition was calculated with the monthly natural gas consumption data and the remainder fuel oil was assumed to be used as single type of fuel. The unit pollutant emission and unit fuel consumption were set under the mixture condition and the single type fuel condition, separately.

Table 8.1.1 Unit Parameters of Tabriz Power Plant

		UNIT-1
Parameters	Unit	Fuel Oil
Maximum Load	MW	350.0
Electricity Generation	MW	317.5
Fuel Consumption	t/h	72.0
Wet Gas Volume	$10^3 m^3_N$/h	1,215.0
SO_x Emission Rate	m^3_N/h	777.00
NO_x Emission Rate	m^3_N/h	256.38
PM Emission Rate	kg/h	94.60
Flue Gas Temperature	℃	193.5
Stack Height	m	120.0
Stack Diameter	m	5.0

Table 8.1.2 Unit Parameters of Esfahan Power Plant

		UNIT-3		UNIT-4		UNIT-5	
Parameters	Unit	Only Fuel Oil	Fuel Oil & Natural Gas	Only Fuel Oil	Fuel Oil & Natural Gas	Only Fuel Oil	Fuel Oil & Natural Gas
Maximum Load	MW	120.0	120.0	320.0	320.0	320.0	320.0
Electricity Generation	MW	75.5	97.5	240.0	160.0	170.0	220.0
Fuel Consumption							
Fuel Oil	t/h	19.60	15.10	53.50	13.10	39.00	3.00
Natural Gas	m^3N/h	-	14.05	-	26.35	-	45.00
Wet Gas Volume	$10^3 m^3$N/h	415.0	500.0	1050.0	785.0	820.0	930.0
SO_x Emission Rate	m^3N/h	389.20	202.30	945.00	207.73	889.00	26.95
NO_x Emission Rate	m^3N/h	48.45	87.17	173.84	364.97	115.41	32.63
PM Emission Rate	kg/h	59.2	49.7	266.6	31.1	87.0	14.8
Flue Gas Temperature	℃	147.5	147.5	169.5	169.5	135.0	135.0
Stack Height	m	55.0	55.0	80.0	80.0	80.0	80.0
Stack Diameter	m	2.5	2.5	5.0	5.0	5.0	5.0

$$Q_D = Q_m \times C_M / C_m / D$$
$$H_D = H_m \times C_M / C_m / D$$

Q_D: Daily Pollutant Emission H_D: Daily Gas Volume

Q_m: Unit Pollutant Emission C_M: Monthly Fuel Consumption

C_m: Fuel Consumption at the Monitoring

D: Number of the Days

$$Q_i = Q_D \times U_i / \Sigma \ U_i \times L_i / \Sigma \ L_i$$
$$H_i = H_D \times U_i / \Sigma \ U_i \times L_i / \Sigma \ L_i$$

Qi: Hourly Pollutant Emission   Hi: Hourly Gas Volume

Li: Hourly Load Pattern Σ Li: Daily Total Load

Ui: Facility Unit Capacity Σ Ui: Total Capacity

(2) Emission Sources Summary

The calculation of the other emission sources like large factories, small and medium factories and establishments, households and vehicles are explained in **Appendices 8-2, 8-3, and 8-4**.

The pollutant emission sources in both areas are summarized in **Table 8.1.3** and **Table 8.1.4**. Tabriz power plant occupied 52.3 % of SO_x, 44.8 % of NO_x, 8.2 % of PM, and Esfahan power plant occupied 14.8 %, 36.8 % and 5.3 % of SO_x, NO_x, and PM. Accuracy is low in the data of the other emission sources, in this Study.

Large emission sources with high stacks are treated as point sources, major road traffics as line sources, and non-pointed sources like small, medium industries, households, and minor road traffics as area sources in the simulation model.

Table 8.1.3 Summary of Emission Sources in Tabriz Area

Emission Source	Type	Pollutant Emission Amounts		
		SO_x	NO_x	PM
Tabriz Power Plant	Point	30,019	7,855	1,279
Large Factories	Point	15,462	2,658	13,215
Small&Medium Factories	Area	5,302	830	201
Households	Area	4,097	1,334	218
Major Road Traffic	Line	45	117	20
Minor Road Traffic	Area	2,439	4,735	587
Total		57,364	17,529	15,520

Unit: tons/year

8-3

Table 8.1.4 Summary of Emission Sources in Esfahan Area

Emission Source	Type	Pollutant Emission Amounts		
		SO$_x$	NO$_x$	PM
Esfahan Power Plant	Point	28,550	11,774	1,660
Large Factories	Point	157,969	12,517	28,114
Small&Medium Factories	Area	1,995	748	189
Households	Area	1,325	346	46
Major Road Traffic	Line	1,747	4,789	820
Minor Road Traffic	Area	1,364	1,858	299
Total		192,950	32,032	31,128

Unit: tons/year

8.1.2 Annual Average Simulation Model

In the annual average simulation model, one year is divided into seasons and time zones according to the meteorological and pollutant emission patterns. The periodical average concentrations are calculated at first, and subsequently annual average concentrations are calculated from the periodical averages.

(1) Method of Annual Average Calculation

First, calculated are frequencies and averages of the necessary meteorological data by seasons, time zones, wind directions, wind speed classes, and stability classes. Also, pollutant emission rates and wet stack gas volume rates are averaged by seasons and time zones. Strictly speaking, the wet gas volumes are averaged only during the operation periods. Next, concentration contributions from each source to each calculation point are calculated by the averages for each classes. Finally, the annual averages are obtained by the following formula.

$$C_y = \sum_t \left(\sum_s \left(\sum_{rm} F(Q_s, W_{rm}) \cdot f_{rm} \right) \cdot f_t \right)$$

C_y	:	Annual Average Concentration
t	:	Seasons & Time Zones Categories
s	:	Emission Sources Classes
rm	:	Meteorological Classes
$F()$:		Dispersion Model
Q_s	:	Pollutant Emission Rate for Each Source
W_{rm}:		Average of Meteorological Factors by Meteorological

Classes

f_{rm} :   Frequency of Meteorological Conditions
by Seasons & Time Zones

f_t :   Frequency of Seasons & Time Zones

(2) Basic Framework

1) Target Period

Target period of the simulation is one year from June of 1998 through May of 1999.

2) Season and Time Zone

Season and time zone settings of Tabriz area and Esfahan area are shown in Table 8.1.5 and Table 8.1.6.

Table 8.1.5   Season Settings

Area	Summer	Winter
Tabriz	Mar. to Sep.	Oct. to Feb.
Esfahan	Feb. to Aug.	Sep. to Jan.

Table 8.1.6   Time Zone Settings

Area	Morning	Noon	Afternoon	Night	Midnight
Tabriz	6 to 10	11 to 14	15 to 19	20 to 24	1 to 5
Esfahan	6 to 9	10 to 13	14 to 18	19 to 1	2 to 5

3) Meteorological Classes

Wind Directions: 16directions and Calm(Wind speed<= 0.4m/s)

Wind Speed Classes: <=0.4m/s, <=0.9m/s, <=1.9m/s, <=2.9m/s,
<=3.9m/s, <=5.9m/s, <=7.9m/s, <8.0m/s

Atmospheric Stability Classes:

            A(Strong Unstable), AB, B, BC, C, CD,

            dD(Daytime Neutral), nD(Nighttime Neutral),

            E, F, G(Strong Stable)

Atmospheric stability classes were defined with the observed wind speeds, solar radiation, and net radiation according to Pasquill's Stability Index Classes (US Atomic Energy Committee Safety Guide)(Appendix 8-5).

4) Target Emission Sources and Target Pollutants

Target emission sources are all of the sources explained in 8.1.1 and Appendix 8-2, 8-3 and 8-4.

Target Pollutants: SO_2, NO_x, NO_2 and SPM

Generally, pollutants emitted from the sources are called SO_x, NO_x, and Dust or PM(Particulate Matter), and ambient concentrations caused by them are called SO_2, NO_x, NO_2 and SPM(Suspended Particulate Matter). NO_x means the sum of NO and NO_2, and a part of NO_x is converted to NO_2.

5) Meteorological Blocks and Vertical Layers

The simulation model uses the meteorology data at each power plants and its surroundings. Solar radiation and net radiation were observed at each meteorological station in Tabriz and Esfahan plants, and wind directions and wind speeds were at each meteorological station and each three air monitoring stations in the both areas. Each target area was divided into four meteorological blocks and the four stations were defined as representative meteorological stations. The meteorological stations in the power plants were representative stations for the power plant stacks.

Vertical layers were also defined for physical stack heights and wind speeds were corrected for representative height of each layer as in Table 8.1.7.

Table 8.1.7 Vertical Layers Settings

Areas	Layers	Stack Height	Representative Height
Tabriz	1	<=10m	Monitoring Height(10m)
	2	<=40m	25m
	3	<=70m	53.5m
	4	70m<	120m
Esfahan	1	<=10m	Monitoring Height(10m)
	2	<=40m	25m
	3	<=70m	55m
	4	<=100m	80m
	5	100m<	200m

(3) Dispersion Formula

Long-term average type of Plume formula under windy condition and Puff formula under calm condition were used for annual average simulation model. The formulas for point sources like power plants, large factories etc. are given below. For line sources and area sources, the formulas for point sources were analytically or

numerically integrated. The lid was not included into the formulas for line and area sources because of their closeness to the ground.

Windy: Long-term averaging type of Plume formula (Lid included)

$$C(R,z) = \sqrt{\frac{1}{2\pi}} \frac{Q_p}{\frac{\pi}{8} R \sigma_z u} \cdot F$$

$$F = \sum_{n=-3}^{3} \left\{ \exp\left[-\frac{(z - He + 2nL)^2}{2\sigma_z^2} \right] + \exp\left[-\frac{(z + He + 2nL)^2}{2\sigma_z^2} \right] \right\}$$

C:	Pollutant concentrations at calculation points (ppb, μ g/m^3 etc.)
R:	Distances from emission sources (m)
z:	Height of calculation point (m)
Q_p:	Pollutant emission rate (m^3_N/sec, Kg/sec etc.)
u:	Wind speed (m/sec)
He:	Effective stack height
σ_z:	Vertical diffusion width (m)
L:	Lid height (m)

Vertical diffusion width(σ_z) is a function of atmospheric stability and leeward distance X (m), and expressed by the approximation formula as $\sigma_z = \gamma_z \cdot X^{\alpha_z}$ which were made from the Pasquill-Gifford chart. The parameters of γ_z and α_z by each atmospheric stability are shown in **Appendix 8-6**.

Calm: Long-term averaging type of Puff formula (Lid included)

$$C(R,z) = \frac{Q_p}{(2\pi)^{3/2}\gamma} \cdot \sum_{n=-2}^{2} \left\{ \frac{1}{R^2 + \frac{\alpha^2}{\gamma^2}(He - z + 2nL)^2} + \frac{1}{R^2 + \frac{\alpha^2}{\gamma^2}(He + z + 2nL)^2} \right\}$$

$\alpha = \sigma_x / t = \sigma_y / t$

$\gamma = \sigma_z / t$ (α and γ values are shown in **Appendix 8-6**)

t: time passage

The 'lid' means phenomena that an upper inversion layer shuts out the pollutants to pass through like a lid, and the heights of lids were estimated on the results of upper layer observations (Appendix 8-5). The 'lid' is defined as the lowest one among upper layer inversions, and the 'inversion' is defined as layers with increasing temperature by climbing to higher altitudes, and more than 100 meters' depth.

(4) Estimating Formula for Effective Stack Height

Stack gas is assumed to disperse from the effective stack height. The estimations of effective stack heights for emission sources are shown in Table 8.1.8.

Table 8.1.8   Effective Stack Height Settings

Areas	Wind Condition	Point Factory	Line Vehicle	Area Factory	House	Vehicle
Tabriz	Windy	CONCAWE	1.0	20.0	5.0	1.0
	Calm	Briggs	1.0	30.0	10.0	2.0
Esfahan	Windy	CONCAWE	1.0	20.0	5.0	1.0
	Calm	Briggs	1.0	30.0	10.0	2.0

Unit: m

Windy Condition: CONCAWE formula

$$H_e = H_0 + 0.175 \cdot Q_H^{\frac{1}{2}} \cdot u^{-\frac{3}{4}}$$

H_e: Effective Stack Height (m)

H_0:   Physical Stack Height (m)

Q_H: Heat Emission (cal/s)

u: Wind speed at Stack Top (m/s)

$$Q_H = \rho \cdot C_p \cdot Q \cdot (T_G - T_A)$$

ρ: Gas Density at 0°C (1.293 x 10^3 g/m^3)

C_p: Isopiestic Specific Heat (0.24 cal/°K/g)

Q :   Emission Gas Volume (m^{3}N/s)

T_G: Emission Gas Temperature (°C)

T_A: Ambient Temperature (°C)

              (12.0°C at Tabriz, 14.2°C at Esfahan)

Calm Condition: Briggs Formula(Calm)

$$H_e = H_0 + 1.4 \cdot Q_H^{1/4} \cdot (d\theta/dz)^{-3/8}$$

$d\theta/dz$:   Potential Temperature Gradient(°C/m)

Averages of potential temperature gradients by seasons and time zones were also calculated from the results of the upper layer observations(Appendix 8-5).

(5) NO_2 Conversion Model

The following exponential model is used for NO_2 conversion.

$$[NO_2] = [NO_x]_D \cdot \left[1 - \frac{\alpha}{1+\beta} \{ \exp(-Kt) + \beta \} \right]$$

$[NO_2]$:	NO_2 Concentrations
$[NO_x]_D$:	NO_x Concentrations
α:	NO/NO_x Ratios around Emission Source
β:	Approximation Constant for Equilibrium Condition
	NO/NO_x Ratios far from Emission Source
t:	Diffusion Time(sec)

$$K = F_K \cdot u \cdot [O_3]_B \cdot F_{o3}$$

F_K:	Experimental Coefficient (s^{-1})
u:	Wind Speed (m/s)
$[O_3]_B$:	Background O_3 Concentrations (ppm)(Appendix 8-5)

F_{o3} :Correction Factor for O_3 Concentrations

(Only for Parallel Wind, Daytime0.55, Nighttime0.33)

Table 8.1.9   Parameters for NO_2 Exponential Model

Areas	Type	α	β	F_k
Tabriz	Point	0.83	0.30	0.0062
&	Area	0.83	0.30	0.0620
Esfahan	Line	0.80	0.30	0.2300

O_3 data in Tehran City were used because of no O_3 measurement in Tabriz and Esfahan areas (Appendix 8-5).

(6) Wind Speed Estimation at Stack Top

Wind speeds at stack top heights were estimated by the following formula.

$$U_z = U_s \cdot \left(\frac{Z}{Z_s}\right)^p$$

U_z :　　　Wind speed at Stack Top with Z meters height

U_s :　　　Surface wind speed with Z_s meters height

p :　　　Wind speed correction factors by Atmospheric Stability

　　　　　Classes(Appendix 8-5)

Wind speed correction factors were calculated for each atmospheric stability classes with the results of the upper observations at surface (10 meters) and upper layer (100 meters).

(7) Atmospheric Stability Classes and Dispersion Parameters

σ_z parameters in long-term Plume formula and α and γ in long-term Puff formula express the diffusion conditions of atmosphere, and they are functions of the atmospheric stability and downwind distances. The atmospheric stability classes are decided with the observed wind speeds, solar radiation, and net radiation. However, the stability classes are decided for surface layers, and the stability tends to become neutral in upper layers where effect of solar radiation is reduced.

The correspondences of the atmospheric stability classes decided by the observed data and the diffusion parameters for the dispersion simulation model are considered as a kind of parameters for model calibrations. Generally, the diffusion parameters are calibrated to simulate the measured concentrations. In such cases, meteorologically rational relationships among each parameter should be kept. The diffusion parameters settings by seasons, time zones, vertical layers, and stability classes for Tabriz and Esfahan areas are shown in Appendix 8-5.

The pollutants emitted from line and area sources are diluted to some extent because of turbulence inside roads or among buildings. This kind effects are considered as initial diffusion width (σ_{z0})(Appendix 8-5).

(8) Calculation Points

Pollutants concentrations were calculated at the automatic continuous monitoring stations and center points of each 1 km spans grid from each emission source. The target area of Tabriz expands 65 km in east-west direction, and 82 km in north-south direction, and results in 5330 center points. The ranges of Esfahan are 69 km in east-west direction, and 80 km in north-south direction, and calculation points are 5520.

The calculation heights were defined as the height of the sampling holes at the monitoring stations, and 1.5 meters at each grid center.

8.1.3 Simulation Model for Hourly Values and Daily Averages

Hourly values and daily averages of pollutant concentrations were calculated with the hourly meteorological conditions and the hourly pollutants emissions from the target power plants. The methods for the hourly emission conditions and the simulation models including dispersion formulas etc. were the same as to the ones for the annual averages. Because the daily averages from small numbers of hourly values tend to cause eccentric averages, the daily averages were calculated for the data sets with equal to or more than 20 hourly data.

8.1.4 Dispersion Model under Special Meteorological Conditions

Because the effects of the building around the stacks and the topography were estimated with wind tunnels experiments in Japan, only a few simulations were conducted during actual EIA processes. However, some of the models like Gifford Model, Huber-Synder Model, and Terrain Model were used for calculating the downwind profiles of hourly concentrations, and the results were compared with the ones by usual plume model including σ_y parameter.

(1) Emission

Pollutant emissions and stack gas volumes were calculated under the conditions of maximum loading of all units for all pollutants to estimate the maximum pollutant concentrations.

Table 8.1.10   Emission Conditions under Maximum Loading at Tabriz PP

Parameters	Unit	Unit1+2 Fuel Oil	Gas Turbine Natural Gas
Maximum Load	MW	700.0	32.0
Wet Gas Volume	$10^3 m^3_N/h$	2678.74	342.76
SO_x Emission Rate	m^3_N/h	1713.1	0.0
NO_x Emission Rate	m^3_N/h	565.2	12.3
PM Emission Rate	kg/h	208.6	0.0
Flue Gas Temparature	℃	193.5	500.0
Stack Height	m	120.0	12.0
Stack Diameter	m	7.07	2.4

Table 8.1.11 Emission Conditions under Maximum Loading at Esfahan PP

Parameters	Unit	UNIT-3		UNIT-4		UNIT-5	
		Only Fuel Oil	Fuel Oil & Natural Gas	Only Fuel Oil	Fuel Oil & Natural Gas	Only Fuel Oil	Fuel Oil & Natural Gas
Maximum Load	MW	120.0	120.0	320.0	320.0	320.0	320.0
Wet Gas Volume	$10^3 m^3_N/h$	659.603	615.385	1400.000	1570.000	1543.529	1352.727
SO_x Emission Rate	m^3_N/h	618.60	248.98	1260.00	415.45	1673.41	39.20
NO_x Emission Rate	m^3_N/h	77.01	107.29	231.79	729.94	217.24	47.46
PM Emission Rate	kg/h	94.09	61.11	355.47	62.10	163.76	21.53
Flue Gas Temperature	°C	147.5	147.5	169.5	169.5	135.0	135.0
Stack Height	m	55	55	80	80	80	80
Stack Diameter	m	2.5	2.5	5.0	5.0	5.0	5.0

(2) Short - Term Plume Formula

Short - term Plume formula expresses lateral distributions of pollutant concentrations with σ_y (lateral diffusion width), and maximum concentrations occur on the center line of plume (y=0).

$$C(x,y,z) = \frac{Q_p}{2\pi\sigma_y\sigma_z u} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot F$$

$$F = \left\{\exp\left[-\frac{(z-He)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+He)^2}{2\sigma_z^2}\right]\right\}$$

x : Distances from Emission Source to Calculation Points in Downwind Direction (m)

y : Lateral Distances from Plume Center Line (m)

σ_y : Lateral Diffusion Width (m)

Note: The other parameters are as the same as to the ones of long-term Plume formula

The pollutant concentrations at the center line (y=0) and the surface (z=0) were calculated with the above formula and the approximation formula of Pasquill - Gifford chart. The field experiments for Pasquill - Gifford chart had obtained diffusion widths for three minutes, and consequently the hourly lateral diffusion widths σ_y were calculated as the followings with temporal dilution factor C.

$$\sigma_{y60} = C \cdot \sigma_{y3}$$

$$C = \left(\frac{60}{3}\right)^{\frac{1}{5}}$$

(3) Gifford Model

This model was referred in the 'Environmental Impact Assessment Manual for Incinerating Factory', and used often in EIA of incinerating factories. Basic formula is the Plume formula as in the article (2) above, and the following settings are used.

1) Wind speed

Wind speed is set as a half of stack gas velocity.

2) Effective Stack Height

The model assumes the effective stack height to be the physical height because of the strong wind. This assumption means that there is no climbing of pollutant at the exit.

3) Diffusion Width

The plume is assumed to be diluted by the initial diffusion width by the cross-sectional area size of the building around the stack, and the diffusion widths are corrected by the following formula.

$$\Sigma y = \left(\sigma_y + \frac{CA}{\pi} \right)^{1/2}$$

$$\Sigma z = \left(\sigma_z + \frac{CA}{\pi} \right)^{1/2}$$

σ_y, σ_z: Plume Width in Pasquill - Gifford Chart(m)

Σ_y, Σ_z: Corrected Plume Width(m)

A: Cross-sectional Area Size of Building(m^2)

C: Shape Factor

Shape factor takes values from 0.5 to 2.0, and value of 0.5 is usually used to obtain safety side estimation.

(4) Huber-Synder Model

This model is partly included in the 'Nitrogen Oxides Total Abatement Manual (NO_x manual)' (#87), but seldom used in the EIA for thermal power plants. This model also uses the basic Plume formula as in the article (2), and uses corrected effective stack heights and diffusion widths.

1) Effective Stack Heights

Effective stack height is corrected by subtracting the decrease by stack downwash and building downwash.

$$h = h_0 + \Delta h - \Delta h' - \Delta h''$$

h:	Corrected Effective Stack Height(m)
h_0:	Physical Stack Height(m)
Δh:	Plume Rise by CONCAWE Formula(m)
$\Delta h'$:	Decrease by Stack Downwash(m)
$\Delta h''$:	Decrease by Building Downwash(m)

a. Stack Downwash

Decrease by stack downwash ($\Delta h'$) is calculated by the following formula.

In case of $Vs \geqq 1.5$ u; $\Delta h' = 0$

In case of $Vs < 1.5$ u; $\Delta h' = 2 \times (1.5 - Vs/u) \times D$

Vs:	Effluent Velocity of Stack Gas(m/s)
u :	Wind Speed at Stack Top(m/s)
D:	Stack Diameter(m)

b. Building Downwash

Downwash by the building around the stack ($\Delta h''$) is calculated by the following formula. The building effect is negligible when the physical stack height is 2.5 times higher than the tallest building around the stack. The turbulence caused by the building may affect the downwind regions within around 10 times of the building height.

In case of $h_0/h_b \leqq 1.2$;

     $\Delta h'' = 0.333 \Delta h$

In case of $1.2 < h_0/h_b \leqq 2.5$;

     $\Delta h'' = 0.333 - \{(h_0/h_b - 1.2) (0.2563 \Delta h)\}$

In case of $h_0/h_b > 2.5$;

     $\Delta h'' = 0$

         h_b: Building Height(m)

2) Diffusion Width

   a. Vertical Diffusion Width

Vertical diffusion width (σ_z) is calculated by the following formula.

In case of $X < 3L_b$;

     $\sigma_z = 0.7L_b$

In case of $3L_b \leqq X \leqq 10L_b$,

     $\sigma_z = 0.7L_b + 0.067 (X - 3L_b)$

In case of $X > 10L_b$,

     $\sigma_z = \gamma_z (X + X_0)^{\alpha_z}$

X: Downwind Distance(m)

X_0:   Distance from Virtual Point Source Position(m)

         (Difference of $10L_b$ and the Distance where σ_z is equal

         to $1.2L_b$ in Pasquill - Gifford chart)

L_b: Minimum of Building Height and Width(m)

γ_z, α_z :   Parameters of Approximation Formula for Vertical

         Diffusion Width by Pasquill - Gifford chart

b. Lateral Diffusion Width

Lateral diffusion width (σ_y) is calculated in the following formula.

In case of $h_0 / h_b > 1.2$;

$$\sigma_y = \gamma_y \cdot X^{\alpha_y}$$

In case of $h_0 / h_b \leqq 1.2$;

     When $X < 3L_b$,

$$\sigma_y = 0.35 L_b'$$

     When $3L_b \leqq X \leqq 10L_b$,

$$\sigma_y = 0.35 L_b' + 0.067 \ (X - 3L_b)$$

     When $X > 10L_b$,

$$\sigma_y = \gamma_y \ (X + X_0')^{\alpha_y}$$

X_0':   Distance from Virtual Point Source Position(m)

         (Difference of $10L_b$ and the Distance where σ_y is equal

         to $0.35 L_b' + 0.5 L_b$ in Pasquill - Gifford chart)

L_b':   If $h_w < 10 h_b$ then h_w, If $h_w \geqq 10 h_b$ then h_b

γ_y, α_y :Parameters of Approximation Formula for Lateral

         Diffusion Width by Pasquill - Gifford chart

(5) Terrain Model

Terrain effect is estimated by correcting the effective stack height based on the relationship of the relative surface height at calculation point and effective stack height, and atmospheric stability.

1) Terrain Category

Terrain is categorized into complex, simple and intermediate by the relationship of

the relative surface height at calculation point and effective stack height.

In case of $H_i \leq H_0$;   Simple Terrain

In case of $H_0 < H_i < H_c$;   Intermediate Terrain

In case of $H_c \leq H_i$;   Complex Terrain

2) Simple Terrain

Effective stack height is corrected by the following formula.

$H_e' = H_e - H_c$

H_c is minimum of H_0 and H_i

$H_i = Z_r - Z_s$

H_i: Relative Height of the Ground at Calculation Points against Stack Position(m)

Z_r: Height of the Ground at Calculation Point(m)

Z_s: Height of the Ground at Stack Position(m)

3) Complex Terrain

a. Effective Stack Height

Effective stack height is corrected by the following formula.

H_e' is maximum of $H_e - (1 - F_t) \times H_i$ and $H_e \times F_t$ (not less than 10 meters)

F_t: Correction Factor

(Under Stability of A to D:0.5, E to G:1.0)

b. Dilution Factor

Calculated concentrations are corrected by multiplying the following dilution factor.

Under Stability of A to D; $C = 1.0$

Under Stability of E to G;

If $\Delta H_r \leq 0m$ then; $C = 1.0$

If $0 < \Delta H_r < 400m$ then; $C = (400 - \Delta H_r) / 400$

If $400m \leq \Delta H_r$ then; $C = 0.0$

$\Delta H_r = H_t + H_r - H_e$

H_r: Receptor Height at Calculation Point

(Height of Sampling Hole above Ground)(m)

4) Intermediate Terrain

Concentrations are calculated as complex and simple terrain conditions, and one of higher value is adopted.

8.2 Annual Average Concentration

The above mentioned (Article 8.1.2) simulation model was used to calculate annual average concentrations. All of the emission sources were used in the first series of the calculation to calibrate the model parameters to reproduce the measured concentrations. Finally, the contributions from the power plants were calculated with the calibrated parameters.

(1) Reproducibility of the Simulation Model

Although the input data were collected as much as possible as in Article 8.1.1, the reproducibility of the model was not enough. As the major cause was the insufficient data on emission sources, the improvement of the simulation model is recommended in Chapter 9. The scatter diagrams to show conformity of the measured and the calculated concentrations of the pollutants are included in Appendix 8-7, and the concentrations maps by all of the emission sources are in Appendix 8-8.

(2) Annual Average Concentration Distribution

Comparisons of the maximum concentrations of SO_2, NO_2 and SPM in the target areas with the air quality standards are shown in Table 8.2.1. The contributions from the power plants for the pollutants in both areas were much less to the air quality standards. The SO_2 concentration in Esfahan shows higher contribution and occupies one sixth of the standard.

Table 8.2.1 Maximum Concentration from Power Plant vs. Air Quality Standard

Pollutant	Tabriz Maximum	Esfahan Maximum	Standard Primary
SO_2(ppb)	1.0	4.9	30
NO_2(ppb)	0.3	1.3	50
SPM(μ g/m^3)	0.1	0.8	75

Although pollutant emission of two power plants were at similar levels, all of the maximum concentrations in Esfahan were higher than the ones in Tabriz. This is because of the meteorological factors, such as weaker wind and more frequent unstable conditions (A to B) in Esfahan.

Annual average concentrations in Tabriz are shown in **Figure 8.2.1** to **Figure 8.2.3**.

The maximum concentrations of all pollutants occurred at ENE with the distance of around 10 km from the stacks and the influences reached the city center area of Tabriz. The extent of the influences were 0.8 to 1.0 ppb for SO_2, 0.2 to 0.3 ppb for NO_2, and 0.1 to 0.2 μ g/m^3 for SPM.

Annual average concentrations in Esfahan are also shown in **Figure 8.2.4 to Figure 8.2.6.** The maximum concentrations of all pollutants occurred at NE with the distance of around 4 km from the stacks and the influences reached the west half of the city center area of Esfahan. The extent of the influences were 2.0 to 3.0 ppb for SO_2, 0.7 to 1.0 ppb for NO_2, and 0.3 to 0.5 μ g/m^3 for SPM.

IRAN, TABRIZ(1998): Annual Average

N
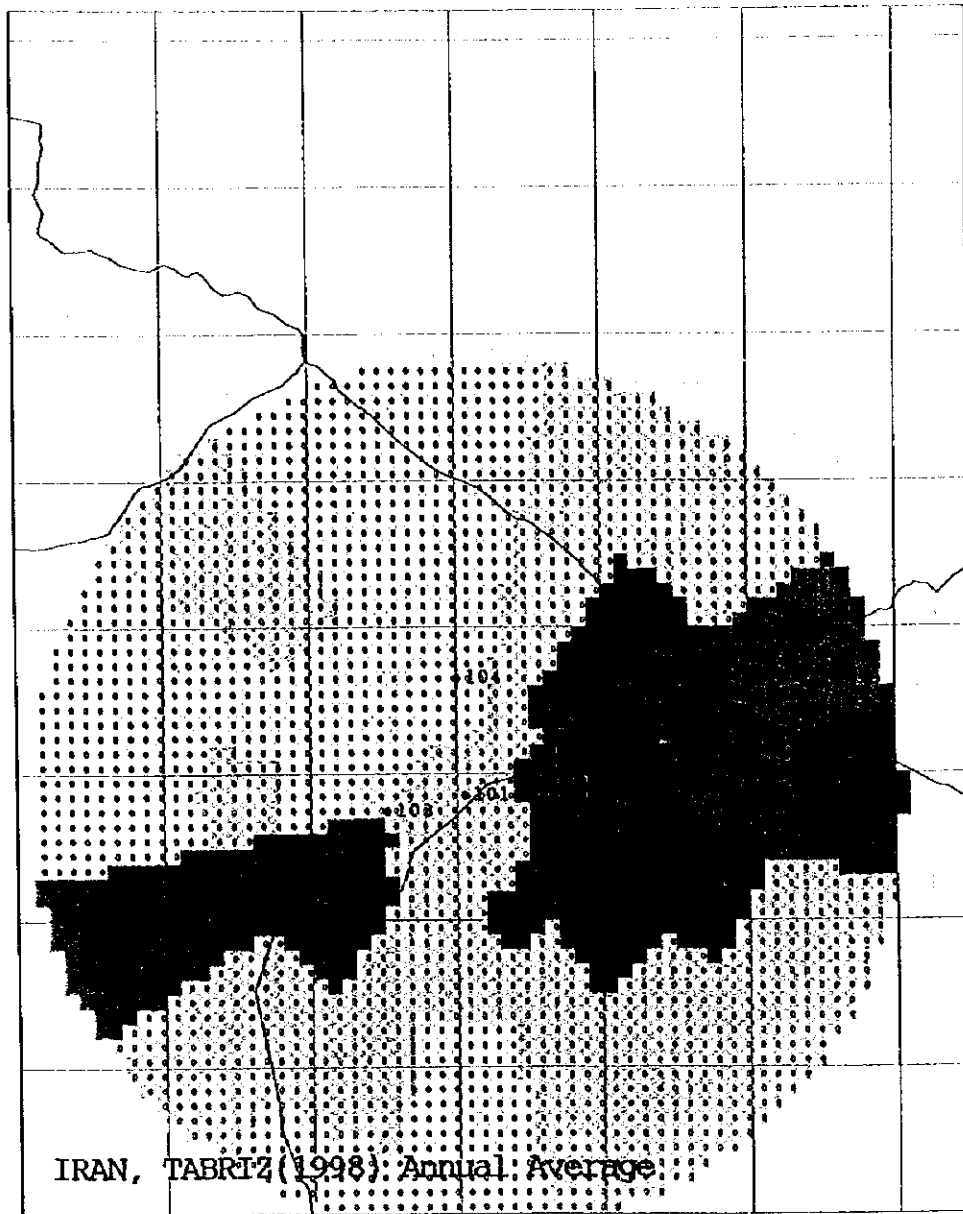
LEGEND

■	.90 < x <= 1.00 (ppb)	38 grids
■	.80 < x <= .90 (ppb)	112 grids
▓	.60 < x <= .80 (ppb)	281 grids
▓	.40 < x <= .60 (ppb)	336 grids
□	.20 < x <= .40 (ppb)	1167 grids
□	.00 < x <= .20 (ppb)	868 grids

0   5   10   15   20 km

Monitoring Stations
    103   Baranloo
    104   Mayan
    105   Qaramalek

Power Plant
    101   Tabriz Power Plant
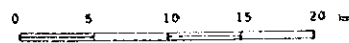
□C MAX=   1.0ppb

Figure 8.2.1   Distribution of Annual Average Concentration (SO_2 from Tabriz P/P)
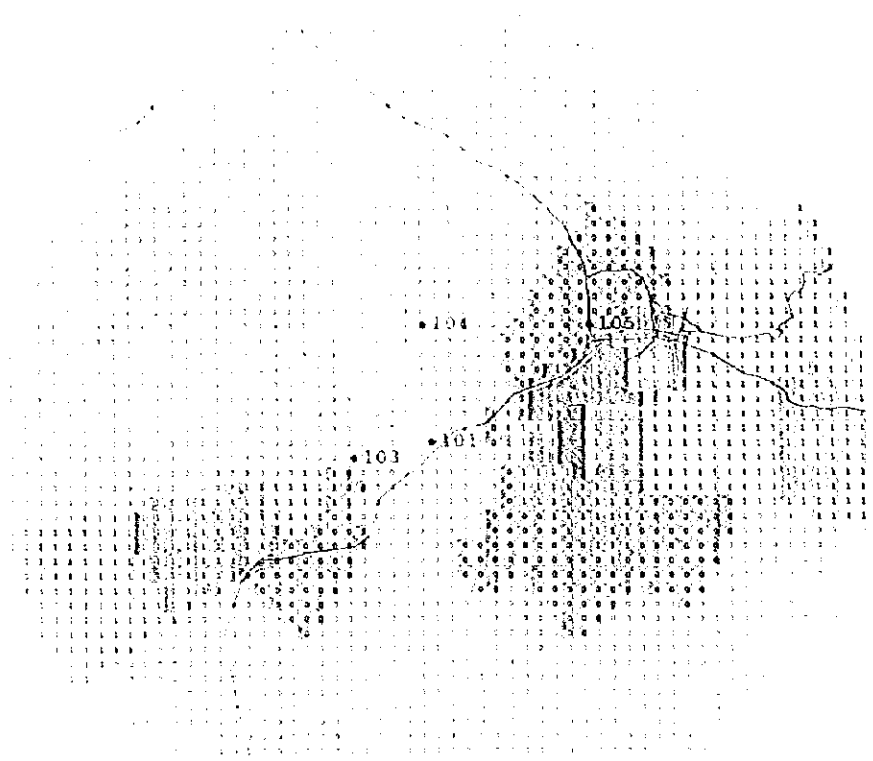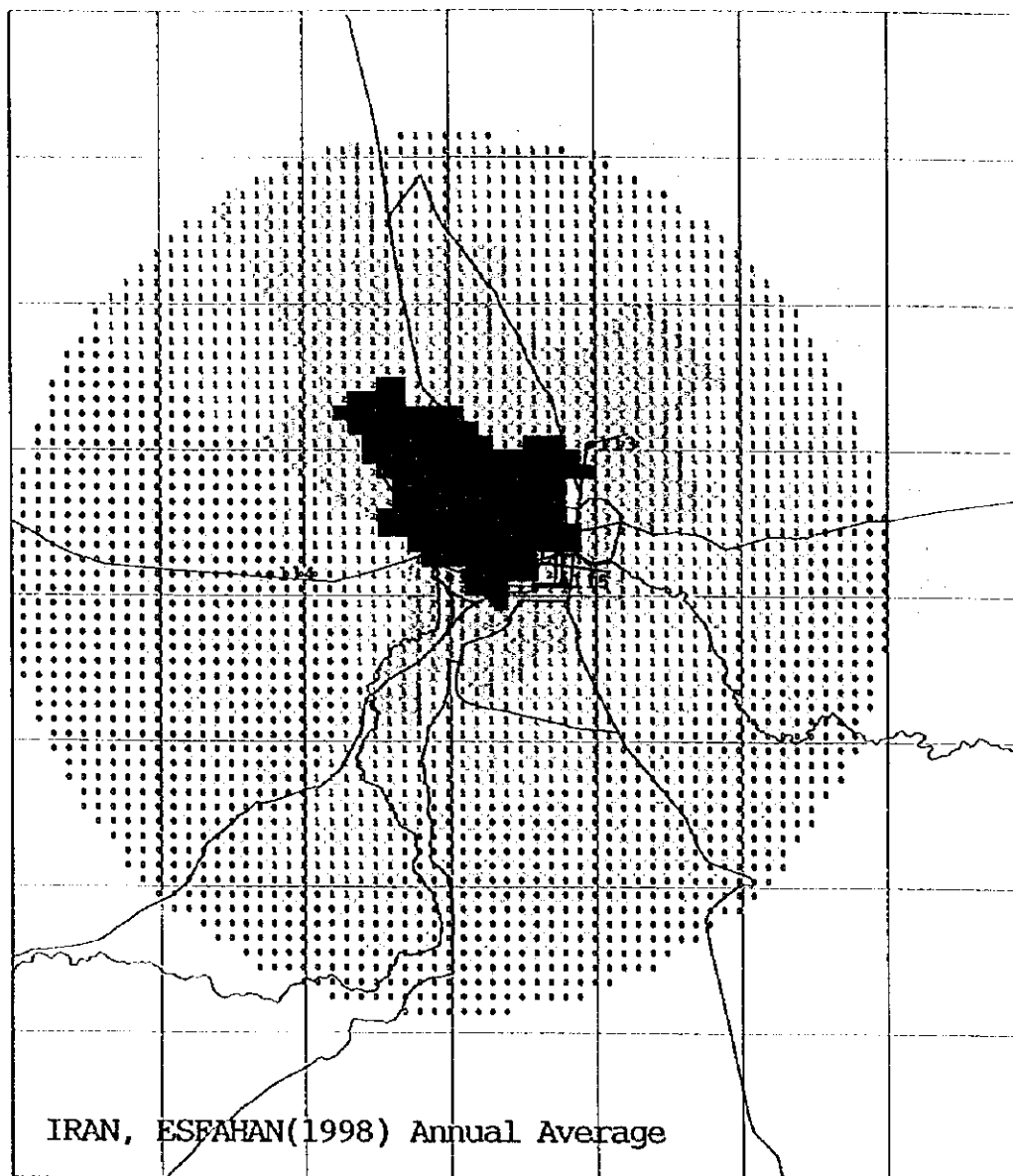
8-19

IRAN, TABRIZ(1998) Annual Average

Figure 8.2.1 Distribution of Annual Average Concentration of Sulphur Dioxide

IRAN, TABRI... Annual A...

N
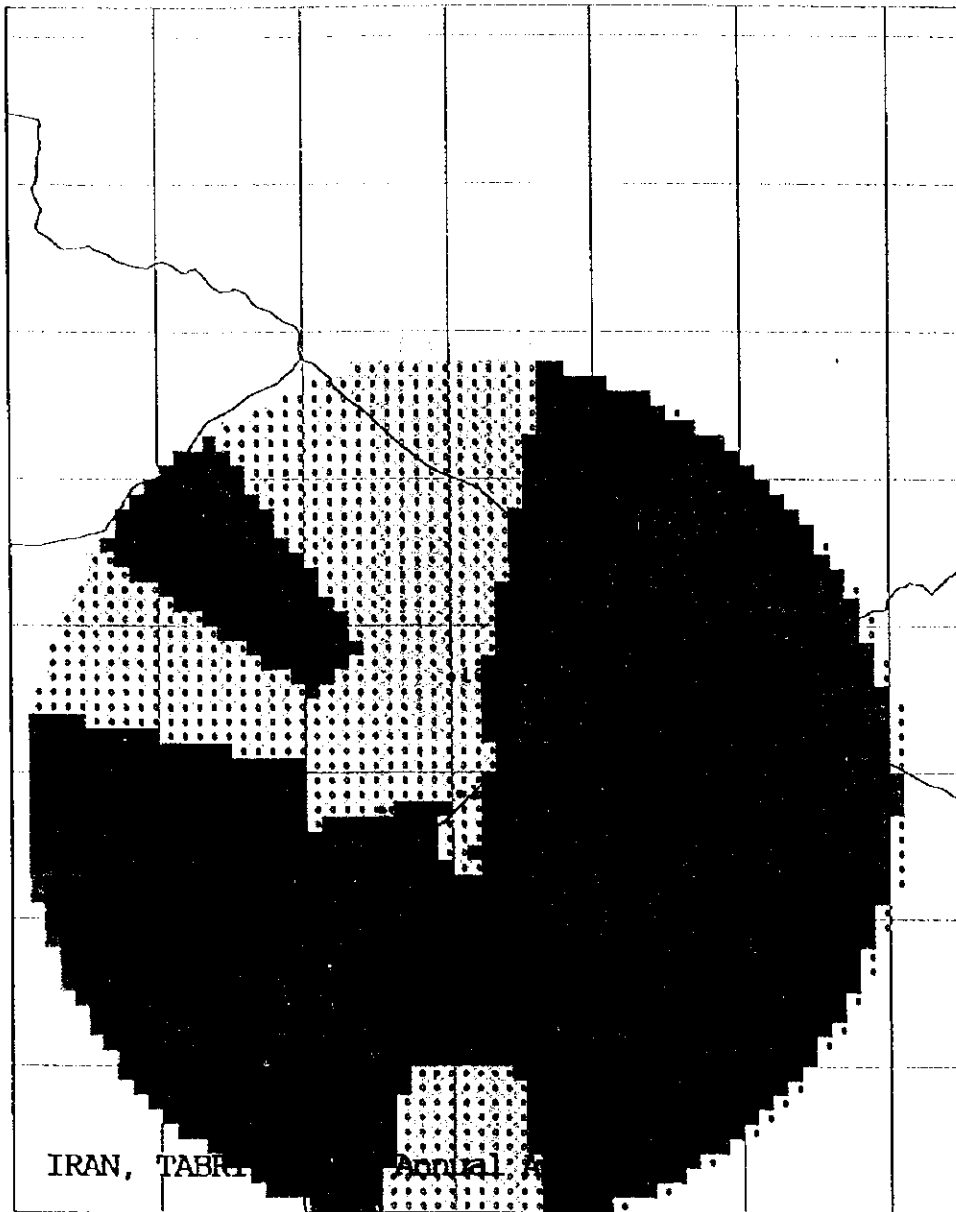
LEGEND

■	.30 < x <= .40 (ppb)	0 grids
■	.20 < x <= .30 (ppb)	317 grids
▨	.10 < x <= .20 (ppb)	626 grids
■	.05 < x <= .10 (ppb)	1165 grids
▢	.01 < x <= .05 (ppb)	694 grids
▢	.00 < x <= .01 (ppb)	31 grids
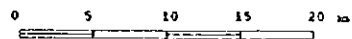
Monitoring Stations
   103 Baranloo
   104 Mayan
   105 Qaranalek

Power Plant
   101 Tabriz Power Plant

▢C MAX=   .3ppb

Figure 8.2.2   Distribution of Annual Average Concentration (NO₂ from Tabriz P/P)

8-20

TABRTZ (1998): Annual Average

IRAN, TABRIZ(1998) Annual Average

N

0   5   10   15   20 km

Monitoring Stations
    103   Baranloo
    104   Mayan
    105   Qaramalek

Power Plant
    101   Tabriz Power Plant

□C MAX=   .1ug/m3

Figure 8.2.3   Distribution of Annual Average Concentration (SPM from Tabriz P/P)

8-21

IRAN, TABRIZ(1998) Annual Average

Figure 5.2.3 Distribution of Annual Average

IRAN, ESFAHAN(1998) Annual Average

N

LEGEND

■	4.5 < x <=	5.0 (ppb)	4 grids
▓	4.0 < x <=	4.5 (ppb)	10 grids
▓	3.0 < x <=	4.0 (ppb)	41 grids
▓	2.0 < x <=	3.0 (ppb)	91 grids
⬚	1.0 < x <=	2.0 (ppb)	519 grids
⬚	.0 < x <=	1.0 (ppb)	2201 grids
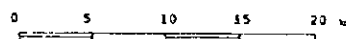
0   5   10   15   20 km
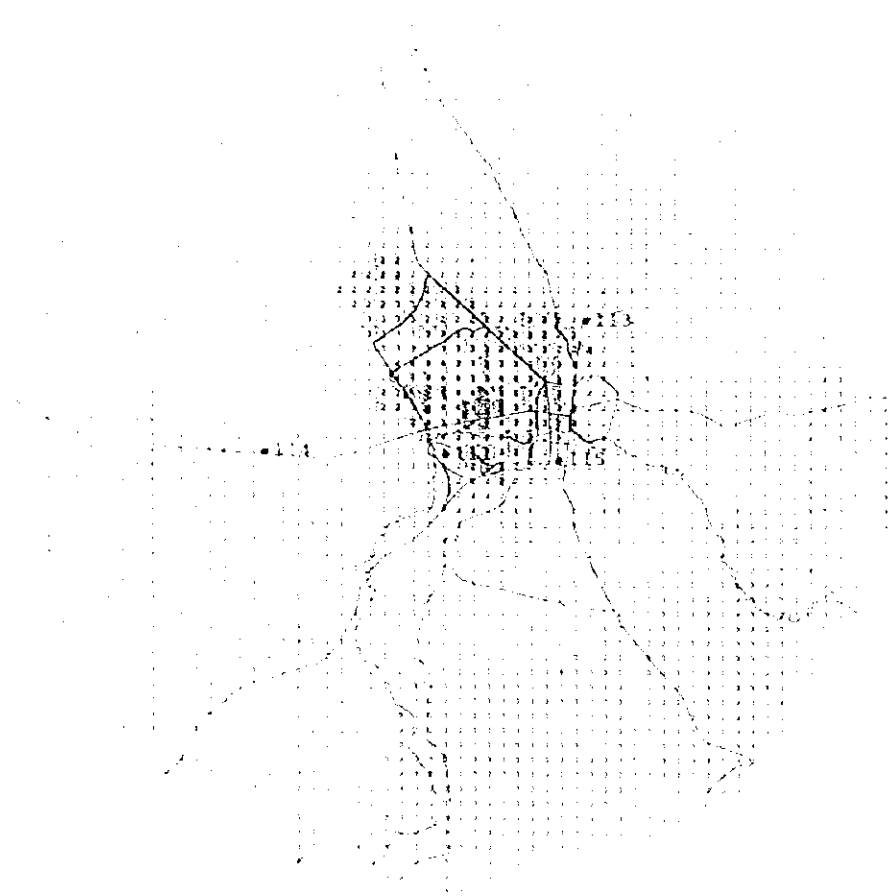
Monitoring Stations
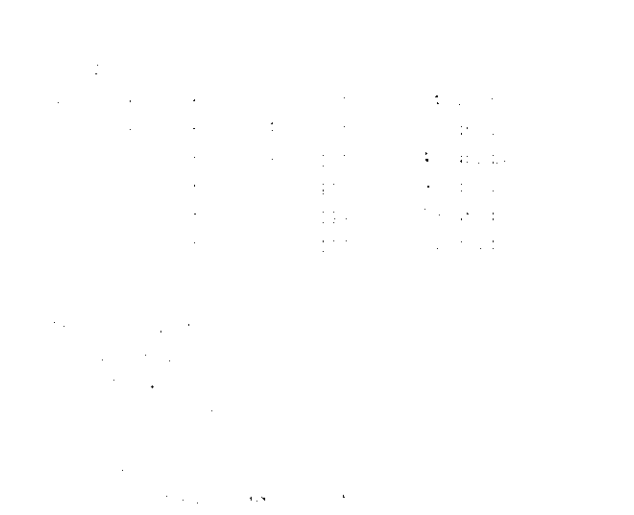   113   Kaveh
   114   Golshahr
   115   Shariati

Power Plant
   111   Esfahan Power Plant

□C MAX=   4.9ppb

Figure 8.2.4   Distribution of Annual Average Concentration (SO₂ from Esfahan P/P)

PM10 EMISSIONS (1990) Annual Average

IRAN, ESFAHAN(1998) Annual Average

N
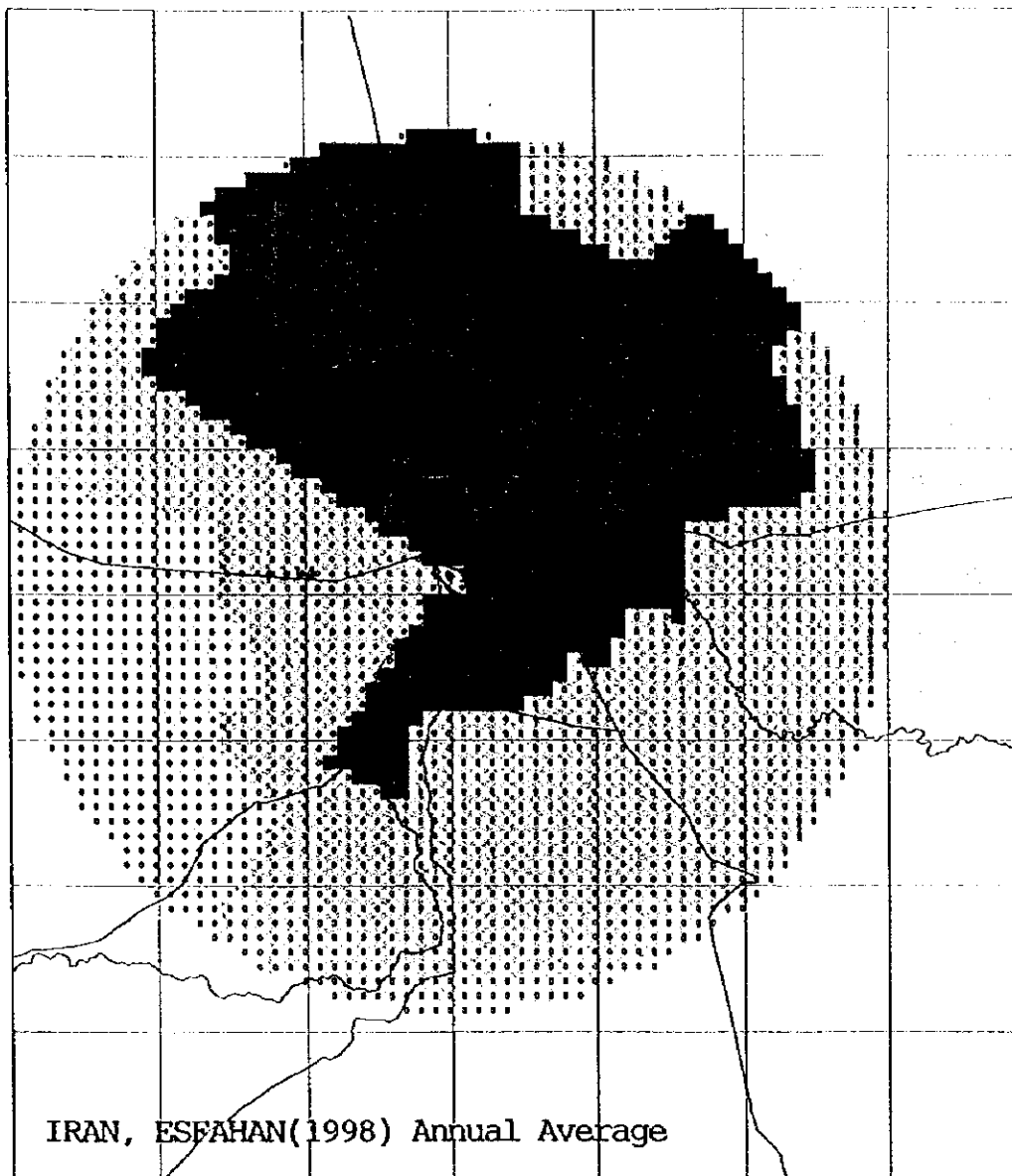
LEGEND

■	1.0 < x <=	1.5 (ppb)	30 grids
■	.7 < x <=	1.0 (ppb)	115 grids
▨	.5 < x <=	.7 (ppb)	264 grids
■	.3 < x <=	.5 (ppb)	700 grids
▢	.1 < x <=	.3 (ppb)	1350 grids
▢	.0 < x <=	.1 (ppb)	407 grids
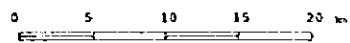
Monitoring Stations
113 Kaveh
114 Golshahr
115 Shariati

Power Plant
111 Esfahan Power Plant

0   5   10   15   20 km

□C MAX=   1.3ppb

Figure 8.2.5   Distribution of Annual Average Concentration (NO₂ from Esfahan P/P)

8-23

IRAN, ESPAHAN(1998) Annual Average

IRAN, ESFAHAN(1998) Annual Average

N
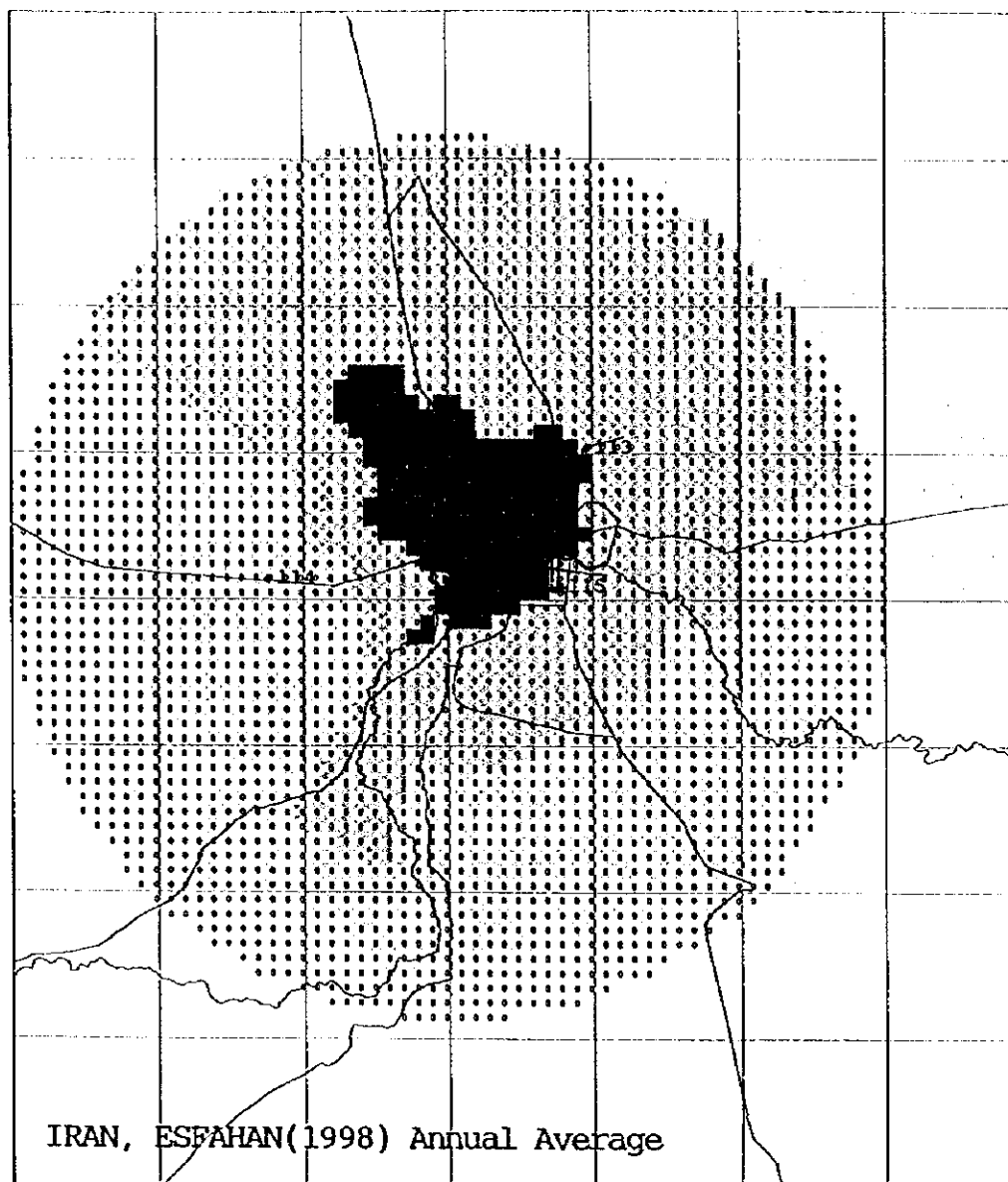
LEGEND

■	.9 < x <=	1.0 (ug/m3)	0 grids
▓	.7 < x <=	.9 (ug/m3)	16 grids
▒	.5 < x <=	.7 (ug/m3)	36 grids
■	.3 < x <=	.5 (ug/m3)	139 grids
□	.1 < x <=	.3 (ug/m3)	1184 grids
□	.0 < x <=	.1 (ug/m3)	1491 grids
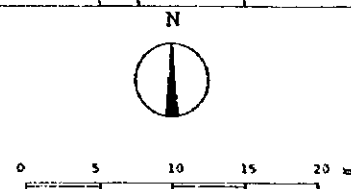
Monitoring Stations
    113 Kaveh
    114 Golshahr
    115 Shariati

Power Plant
    111 Esfahan Power Plant

0   5   10   15   20 km

□C MAX=   .8ug/m3

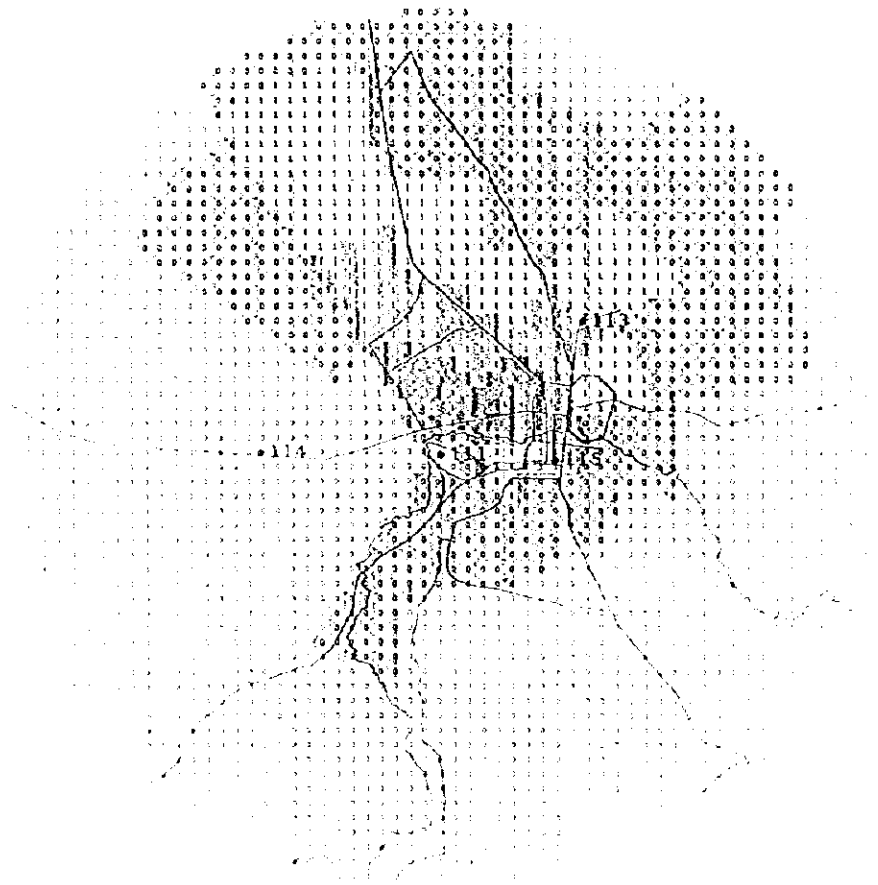Figure 8.2.6   Distribution of Annual Average Concentration (SPM from Esfahan P/P)

8-24
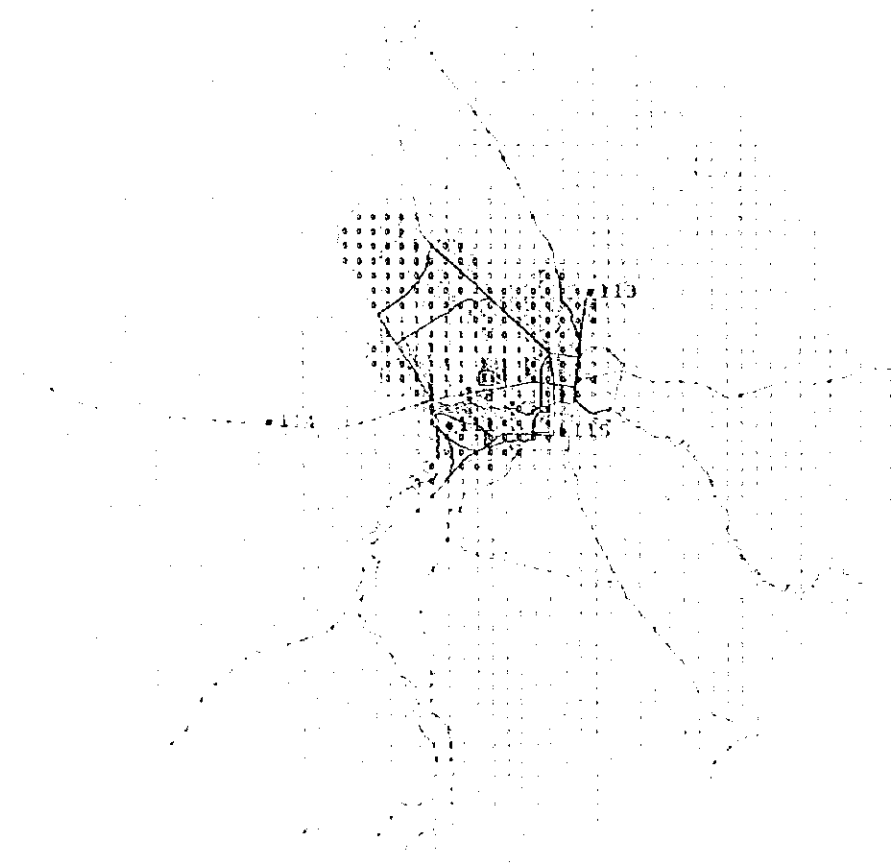
9.XX   PM40CN(1998) Annual Average

Distribution of Vehicle Average Concentration XPM and Clean PPP
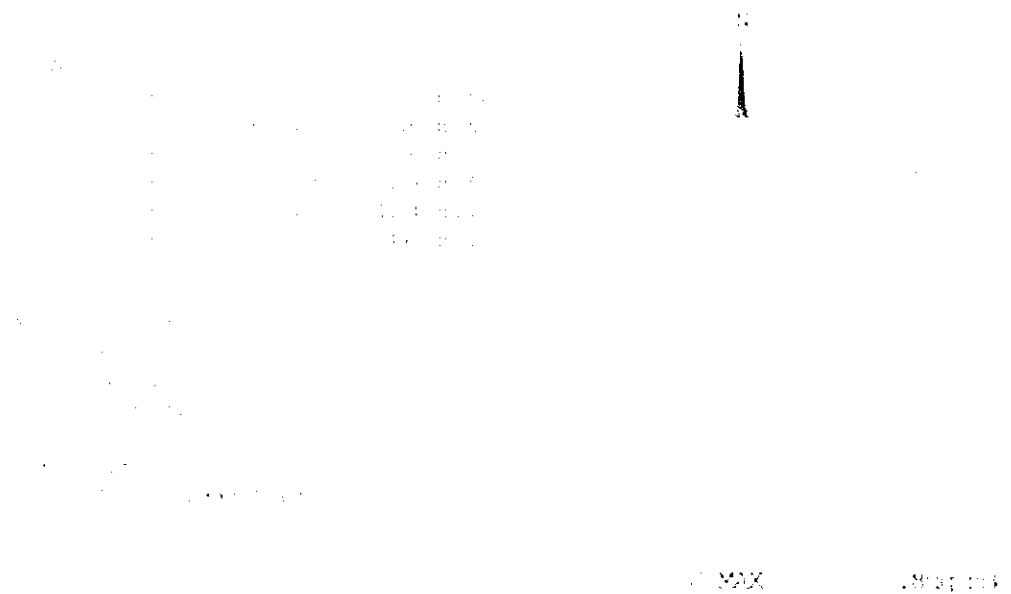
8.3 Hourly Value and Daily Average

The model mentioned in Article 8.1.3 was used for calculating hourly values and daily averages.

(1) Hourly Values

The comparison of the second highest hourly values of maximum pollutants concentrations emitted from the power plants in both areas and air quality standards are shown in Table 8.3.1. No air quality standard is defined for hourly values in Iran, and the standard for SO_2 is for 3 hours' average. One time exceeding is permitted during one year, and the comparisons were conducted with the second highest values, not with the highest values. Although some difference may exist between hourly values and 3 hours' averages, SO_2 concentration was calculated as higher than the standard. Generally, the contributions from the Esfahan power plants were 6 or 10 times higher than the ones from the Tabriz power plants.

Table 8.3.1   Second Highest Hourly Concentrations from Power Plant vs. Standard

Pollutant	Tabriz	Esfahan	Standard
	Second Highest		Secondary
SO_2(ppb)	87.0	621.1	500*
NO_2(ppb)	20.0	129.0	-
SPM(μ g/m^3)	10.6	106.3	-

*: 3 Hours' Average (Secondary Standard)

(2) Daily Average

The comparison of the second highest daily averages of maximum pollutants concentrations emitted from the power plants in both areas and air quality standards are shown in Table 8.3.2. The SO_2 concentration from Esfahan power plant occupied around 40 % of the standard, and the contribution is much for one power plant. The contributions from the Esfahan power plants were also 6 or 8 times higher than the ones from the Tabriz power plants.

Table 8.3.2   Second Highest Daily Average Concentrations from Power Plant vs. Standard

Pollutant	Tabriz	Esfahan	Standard
	Second Highest		Primary
SO$_2$(ppb)	10.0	52.8	140
NO$_2$(ppb)	1.5	11.7	-
SPM(μ g/m^3)	1.2	8.7	260

8.4 Simulations under Special Meteorological Conditions

Four types of models were used for calculating hourly concentrations with the emission conditions of maximum pollutant by each unit and each pollutant, under the influences of buildings and topography.

The terrain from the Tabriz power plant to Kohsrow Shah was considered, where the hill with the relative maximum altitude of 130 meters is between around 4 to 8 km from the plant.   The hill between the Esfahan power plant and Qa-e-Mieh was also considered, and the maximum relative altitude was around 110 meters.

(1) Tabriz

   Table 8.4.1 shows the maximum concentrations calculated for each generation unit under the meteorological conditions of AB to D stability classes and 1.0 to 10.0 m/s wind speeds.   The building height around the stack of unit 1 and unit 2 was 58 meters.

   The calculated values by Huber-Synder model and Terrain model were not so different from the values by Plume model.   The values by Gifford model were around 2 times higher than that of Plume prediction. After all, calculation conditions for this Gifford model were assumed at extreme ones such as for wind speed to be at a half of effluent velocity and effective stack height to be at physical height.   The highest prediction of SO$_2$ concentration (212.2 ppb) by Gifford model was less than the 3 hours' average standard (500 ppb).   The contributions from the gas turbine were very small.

   The SO$_2$ concentration profiles are shown in Figure 8.4.1.

Table 8.4.1   Maximum Concentrations under Special Conditions by Models (Tabriz)

Unit	Pollutant	Model	W.S. m/s	Stab.	Max. ppb	Dist. km
Unit 1 & 2	SO_2	Plume	2.0	AB	93.9	1.9
		Gifford	16.2	AB	212.2	0.6
		Huber-Synder	1.0	AB	104.2	2.5
		Terrain	2.0	AB	95.8	1.9
	NO_x	Plume	2.0	AB	31.0	1.9
		Gifford	16.2	AB	70.0	0.6
		Huber-Synder	1.0	AB	34.4	2.5
		Terrain	2.0	AB	31.6	1.9
	SPM	Plume	2.0	AB	11.4	1.9
		Gifford	16.2	AB	25.8	0.6
		Huber-Synder	1.0	AB	12.7	2.5
		Terrain	2.0	AB	11.7	1.9
Gas Turbine (One Unit)	NO_x	Plume	10.0	AB	2.2	0.6
		Terrain	10.0	AB	2.3	0.6

(2) Esfahan

The maximum concentrations were calculated under the same meteorological conditions for each unit of Esfahan power plant and the results are given in Table 8.4.2.   The heights of the buildings around Unit 3, Unit 4 and Unit 5 were 45, 58 and 58 meters respectively.

The prediction by Terrain model was the highest for Unit 3 and around 2 times higher than the ones by Plume model.   The highest concentration point was located before the peak of the hill (500 meters downwind distance).   The predictions by Gifford model at 400 meters downwind distance were the highest for Unit 4 and 5, and around 2 times higher than the Plume results.

Although the meteorological conditions of the highest concentrations were slightly different, all of the units were assumed at the position of Unit 4 and the common meteorological conditions for the highest concentrations occurrence were selected for calculating the maximum concentrations by all of the contributions from the units (Figure 8.4.2).   The effective stack heights were not shown because of multiple stacks results.

The total SO_2 contributions from Unit 3, 4 and 5 by each model ranged from 545 to 634 ppb, and exceeded the standards.   The highest concentrations appeared at 500 meters distance, but drastically decrease according to lower altitudes.

NO.	He (m)	Cmax (ppm)	Xmax (Km)		
1	1244	.093	2.6	Unit12	CONCAWE&Plume
2	120	.212	.6	Unit12	Gifford

u= 1.0m/s (for Gifford=16.2m/s)
PG-Class:AB
(ppm)
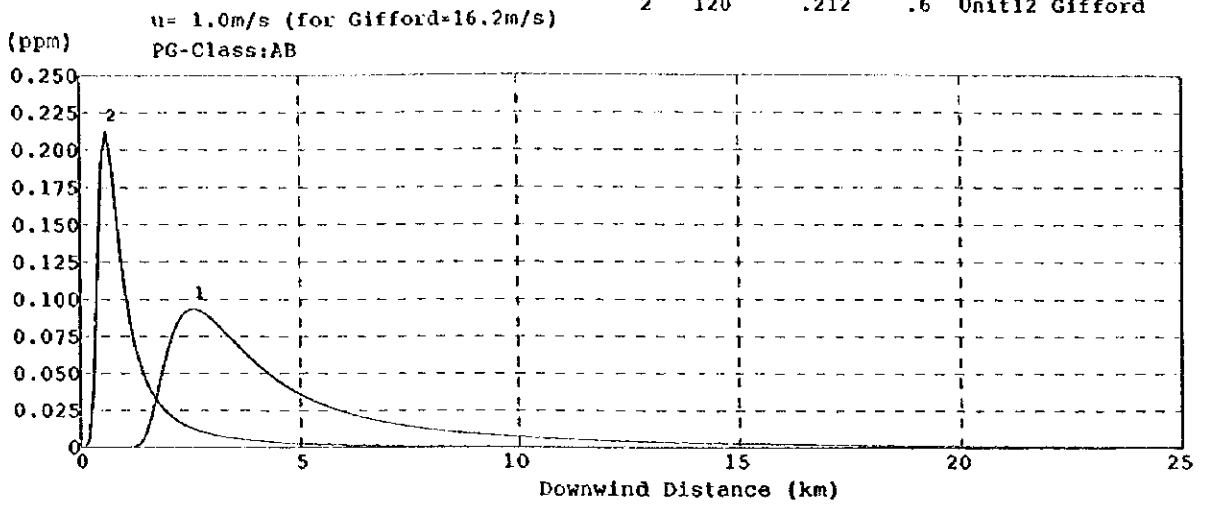
NO.	He (m)	Cmax (ppm)	Xmax (Km)		
1	1244	.093	2.6	Unit12	CONCAWE&Plume
2	1130	.104	2.5	Unit12	Huber&Synder

u= 1.0m/s
PG-Class:AB
(ppm)
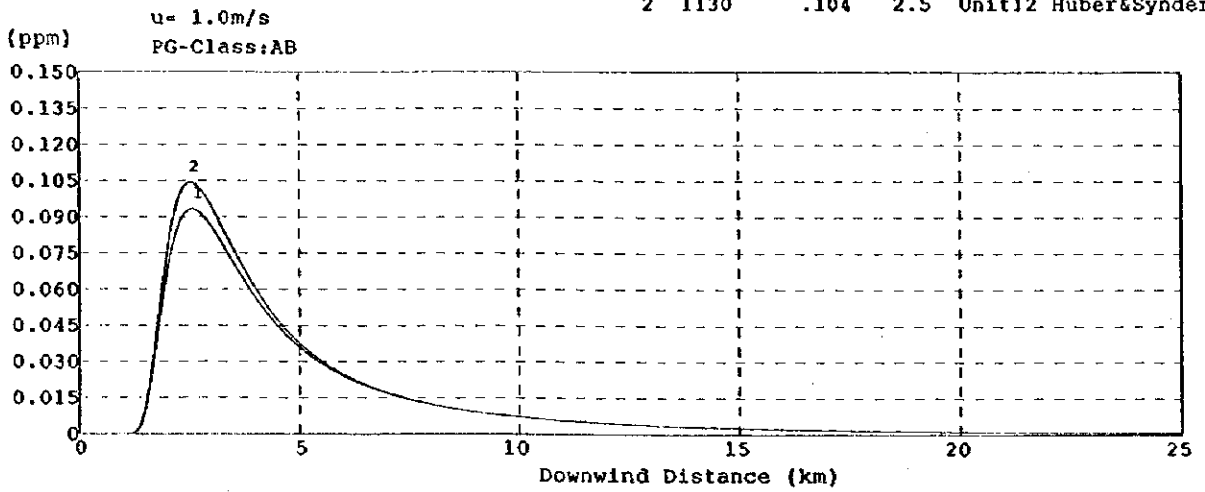
NO.	He (m)	Cmax (ppm)	Xmax (Km)		
1	788	.094	1.9	Unit12	CONCAWE&Plume
2	778	.096	1.9	Unit12	Terrain

u= 2.0m/s
PG-Class:AB
(ppm)

Figure 8.4.1   Maximum SO_2 Profiles by Each Model (Tabriz)

Table 8.4.2 Maximum Concentrations under Special Conditions by Models (Esfahan)
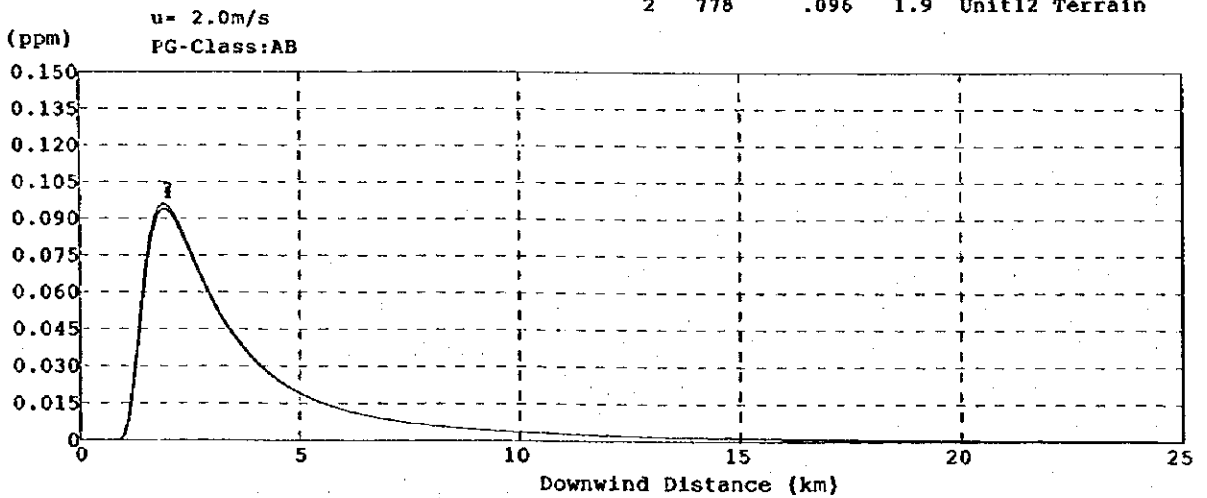
Unit	Pollutant	Model	W.S. m/s	Stab.	Max. ppb	Dist. km
Unit3	SO_2	Plume	1.0	AB	122.9	1.5
		Gifford	28.7	BC	167.0	0.4
		Huber-Synder	1.0	AB	201.0	1.3
		Terrain	10.0	AB	211.8	0.5
	NO_x	Plume	1.0	AB	22.4	1.5
		Gifford	26.8	BC	31.0	0.4
		Huber-Synder	1.0	AB	36.4	1.3
		Terrain	10.0	AB	38.5	0.5
	SPM	Plume	2.0	AB	18.7	1.5
		Gifford	28.7	BC	25.4	0.4
		Huber-Synder	1.0	AB	30.6	1.3
		Terrain	10.0	AB	32.2	0.5
Unit4	SO_2	Plume	2.0	AB	127.4	1.5
		Gifford	16.1	AB	311.6	0.4
		Huber-Synder	1.0	AB	190.0	1.8
		Terrain	10.0	AB	156.6	0.5
	NO_x	Plume	2.0	AB	68.3	1.5
		Gifford	18.0	AB	161.0	0.4
		Huber-Synder	1.0	AB	101.9	1.8
		Terrain	10.0	AB	73.8	0.5
	SPM	Plume	2.0	AB	35.9	1.5
		Gifford	16.1	AB	87.9	0.4
		Huber-Synder	1.0	AB	53.6	1.8
		Terrain	10.0	AB	44.2	0.5
Unit5	SO_2	Plume	1.0	AB	186.8	1.9
		Gifford	16.3	AB	407.0	0.4
		Huber-Synder	1.0	AB	279.2	1.7
		Terrain	1.0	AB	179.4	2.0
	NO_x	Plume	1.0	AB	24.3	1.9
		Gifford	16.3	AB	52.9	0.4
		Huber-Synder	1.0	AB	36.3	1.7
		Terrain	1.0	AB	23.3	2.0
	SPM	Plume	1.0	AB	18.3	1.9
		Gifford	16.3	AB	39.8	0.4
		Huber-Synder	1.0	AB	27.3	1.7
		Terrain	1.0	AB	17.6	2.0

NO.	He (m)	Cmax (ppm)	Xmax (Km)		
1******		.417	1.9	Units	CONCAWE&Plume
2******		.545	.4	Units	Gifford

u= 1.0m/s (for Gifford=28.7m/s)

PG-Class:AB

(ppm)

Downwind Distance (km)

NO.	He (m)	Cmax (ppm)	Xmax (Km)		
1******		.417	1.9	Units	CONCAWE&Plume
2******		.626	1.7	Units	Huber&Synder

u= 1.0m/s

PG-Class:AB

(ppm)

Downwind Distance (km)

NO.	He (m)	Cmax (ppm)	Xmax (Km)		
1******		.332	.8	Units	CONCAWE&Plume
2******		.634	.5	Units	Terrain

u=10.0m/s
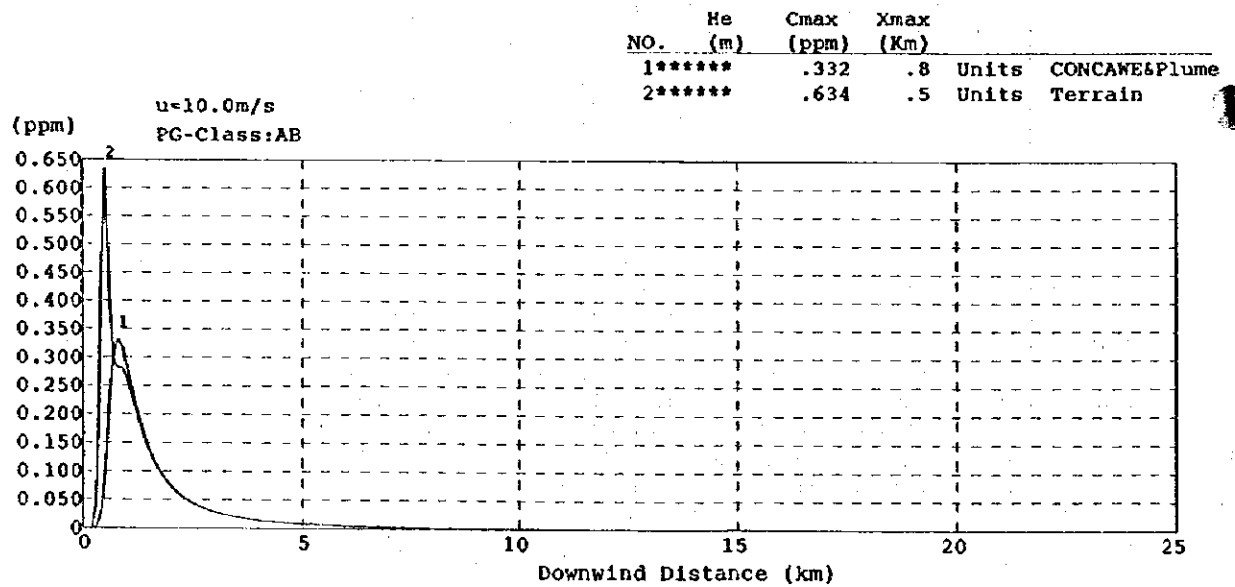
PG-Class:AB

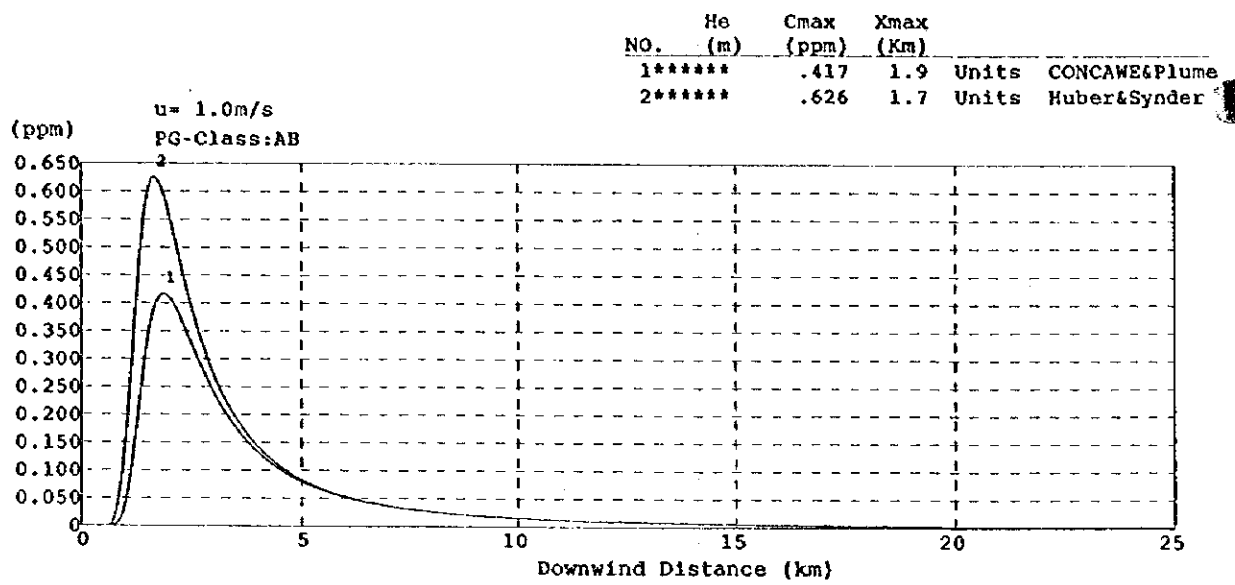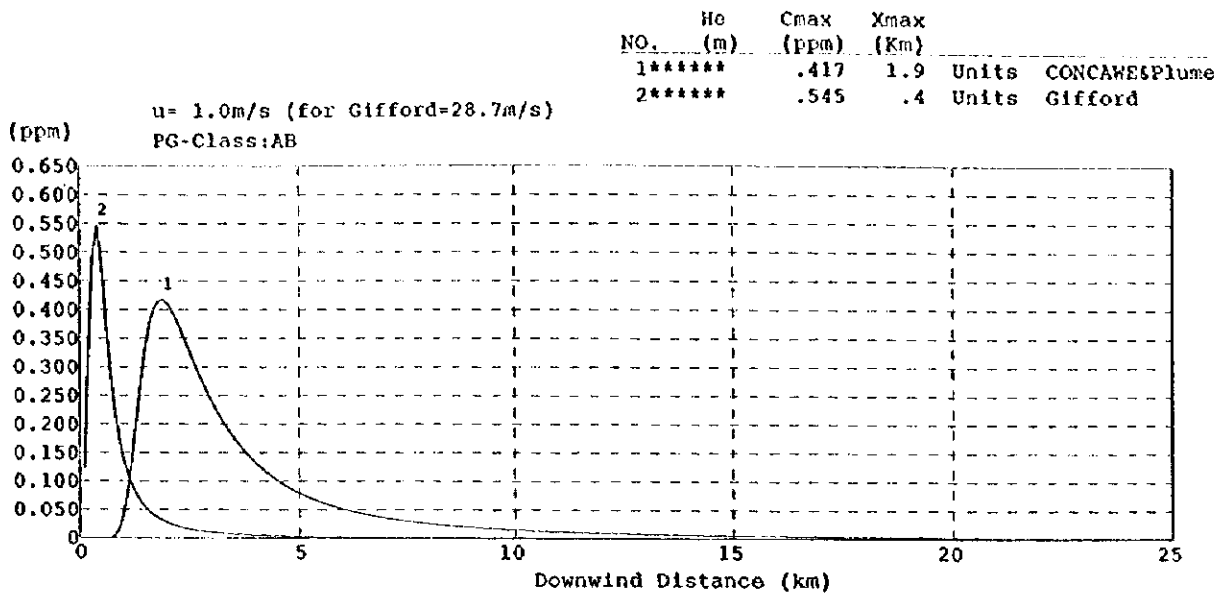(ppm)

Downwind Distance (km)

Figure 8.4.2   Maximum SO₂ Profiles by Each Model (Esfahan)

8-30

8.5 Summary of the Simulation Results

All of the calculated contributions from the Tabriz power plant for annual average, daily averages, hourly values, and values under special meteorological conditions have never exceeded the standards. SO_2 concentrations showed high values compared with the other pollutants, and reached more than 200 ppb against 500 ppb of the 3 hours' average standard in some cases under special meteorological conditions. However, the fuel will be changed to natural gas and SO_x emission will be drastically reduced, and SO_2 from the power plant will not be problematic.

The contribution from the Esfahan power plant to SO_2 annual average concentration is high and reached one sixth of the standard. The SO_2 contributions from the power plant are also high for daily averages and hourly values, and the hourly value exceeded the standard. Estimation considering the special meteorological conditions also showed that the hourly SO_2 concentration probably exceeded the standard. However, the fuel will be changed to natural gas, and more than 50 % of conversion has been finished for summer. After the conversion is completed, hourly SO_2 concentrations will be improved and satisfy the standard. Measured NO_2 concentrations in Esfahan area were relatively high, but the contributions from the power plant were calculated as little. The cause is considered rather vehicles than the power plant.

As a result, the SO_2 concentrations predicted as the power plants to be the highest contributors will be reduced by the fuel conversion to natural gas in both of the Tabriz and Esfahan power plants. Relatively high NO_2 concentrations in the Esfahan area are probably caused by vehicles, and the detailed regional simulation is necessary for the confirmation.

CHAPTER 9 CHEMICAL ANALYSES

9.1 Introduction

Particulates and gaseous pollutants collected in the target areas and at Tabriz and Esfahan Power Plants were chemically analyzed as in Table 9.1.1.

Table 9.1.1 Chemical Analyses in the Study

Samples	Chemicals	Principles	Laboratories
SPM	V, Ni, Zn, Pb	Atomic Absorption	U. of Tehran
Settled Dust	V, Ni, Zn, Pb	Atomic Absorption	U. of Tehran
Soot	V, Ni, Zn, Pb	Atomic Absorption	U. of Tehran
Passive Sample	NO_2 and SO_2	Ion Chromatography	Jihad
Passive Sample	NOx	Absorptiometry	Jihad

Chapter 6 gives details of sampling from ambient air; frequencies of samplings, sampling devices, and sampling methods. Chapter 7 describes soot sampling from stack gases of the Plants.

Metals - vanadium (V), nickel (Ni), zinc (Zn) and lead (Pb) - were analyzed at the Institute for Environmental Studies, University of Tehran. Nitrogen oxide and dioxides, and sulfur dioxide absorbed into passive samplers were analyzed at Chemical Engineering Department, Research Institute of Jihad, Ministry of Construction Crusade. The JICA Team discussed details of analytical procedures including sample preparation with each laboratory prior to the analysis. Instruction materials handed over to the laboratories are attached as Appendices 9-1 to 9-4.

Impregnating of chemicals into filter paper to be used for passive sampling is described in Appendix 9-5. The impregnation was carried out by the Iranian Counterparts in MOE from the summer monitoring. NOx was originally planned to be analyzed with ion chromatography. However, a preliminary test in Japan using the same kind of equipment with the Jihad's showed difficulty of having good resolution. After discussion, Jihad and the JICA Team concluded to use Absorptiometry.

9.2 Results and Discussion

A) SPM

Appendix 6-3 shows original analytical data of metals in SPM samples at each monitoring station (February/1998 to May/1999). Table 9.2.1 summarizes the data.

Table 9.2.1   Metal Contents in SPM

Station		V	Ni	Pb	Zn
Tabriz	Baranloo	0.01 - 0.19	0.01 - 1.34	0.02 - 1.01	0.08 - 16.4
	Mayan	0.01 - 0.17	0.01 - 0.14	0.01 - 1.19	0.12 - 24.3
	Qaramalek	0.01 - 0.20	0.01 - 0.16	0.13 - 3.09	0.36 - 18.3
Esfahan	Golshahr	0.02 - 0.21	0.01 - 0.21	0.39 - 4.17	0.42 - 26.2
	Kaveh	0.01 - 0.16	0.02 - 0.17	0.13 - 3.84	0.20 - 28.2
	Shariati	0.00 - 0.21	0.01 - 0.33	0.25 - 5.82	0.17 - 11.7
Clarke	Number	135	75	13	70

Unit: μ gram / SPM gram

Each metal is somewhat in a narrow range of concentration in SPM. Average metal existence in the earth is given by Clarke and Washington (#86) as V 135, Ni 75, Pb 13 and Zn 70, all in ppm. One ppm is equivalent to one μ gram/gram of average earth. The contents of V and Ni in SPM are quite low in comparison with the Clarke Number.

Table 9.2.2 was composed to show metal contents in the air extracted from Appendix 6-3. Maximum Pb contents was 273 μ gram/1000m^3 in the air. A Notice under Occupational Safety and Hazard Law of Japan Ministry of Labor (1985) announced evaluation levels of metal concentrations in the working atmosphere. The levels are 30 mg/m^3 for V and 100 mg/m^3 for Pb. The ones for Ni and Zn are not given. The concentrations are higher, because people are supposed to be in the working atmosphere in shorter period. U.S.EPA ruled 1,500 μ gram/1000m^3 air as the maximum allowable Pb in ambient air in three months average. Pb concentrations are far below, in Tabriz and Esfahan, than this limitation.

Pb contents and the ratio of V and Ni in SPM suggest SPM is not generated from soot of power plants, if compared with those in Table 9.2.4 given later.

Fig. 9.2.1 and 9.2.2 are plots of data given in Appendix 6-3 to show annual trends of metal concentrations in the air of Tabriz and Esfahan areas. There is no substantial phenomenon in both areas to be mentioned.

Table 9.2.2   Metals in Ambient Air

Station		V	Ni	Pb	Zn
Tabriz	Baranloo	1 - 10	0 - 131	2 - 98	5 - 818
	Mayan	0 - 7	0 - 5	1 - 51	6 - 821
	Qaramalek	0 - 9	1 - 4	2 - 84	16 - 863
Esfahan	Golshahr	0 - 9	0 - 12	6 - 185	10 - 1,185
	Kaveh	0 - 14	0 - 14	7 - 222	16 - 1,460
	Shariati	0 - 17	1 - 19	9 - 273	18 - 665

Unit: μ gram/1000 m^3 of air

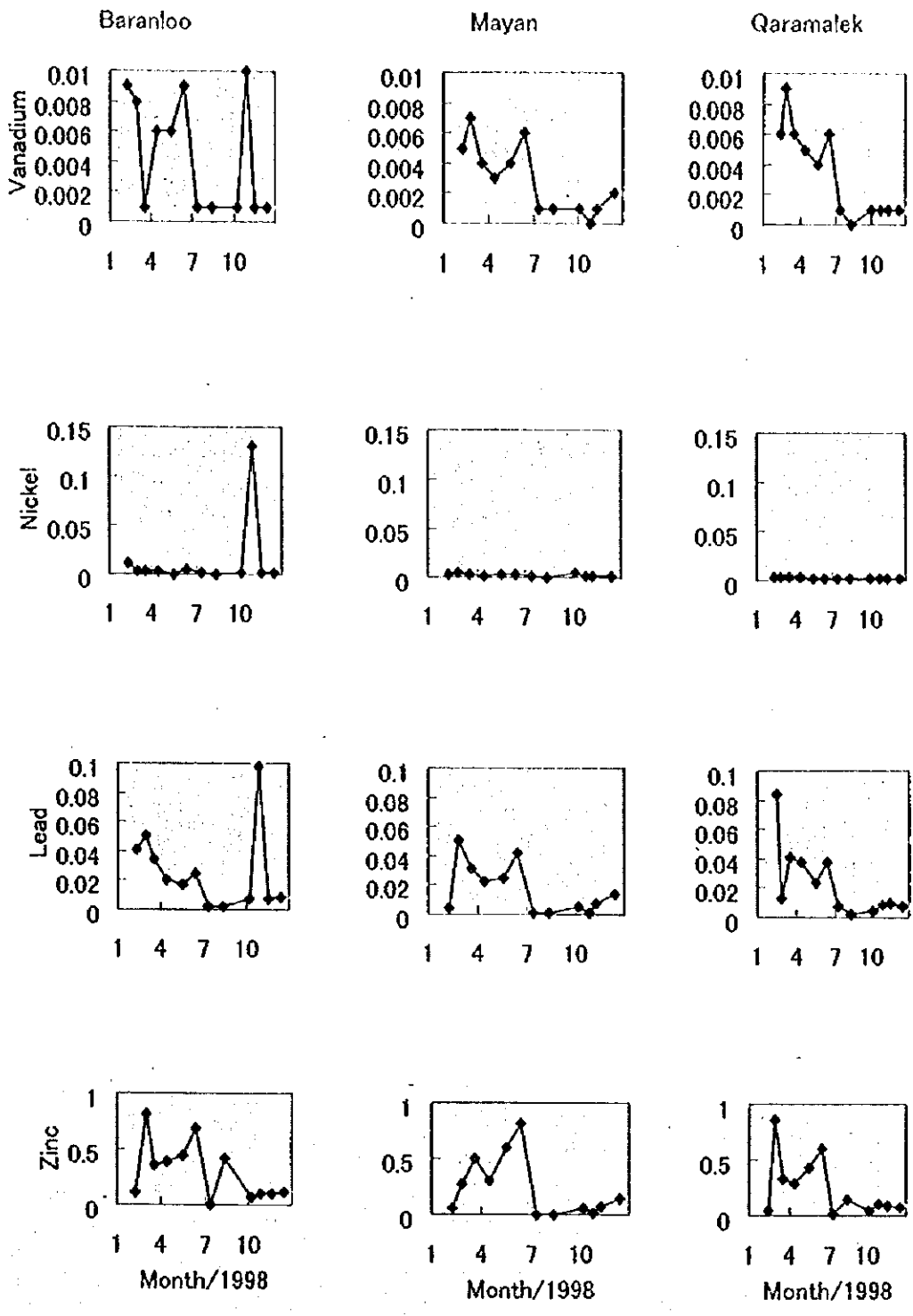**Fig. 9.2.1 Annual Metal Concentration Trends in Air of Tabriz**
Unit: $\mu g/m^3$ vs. Month in 1998
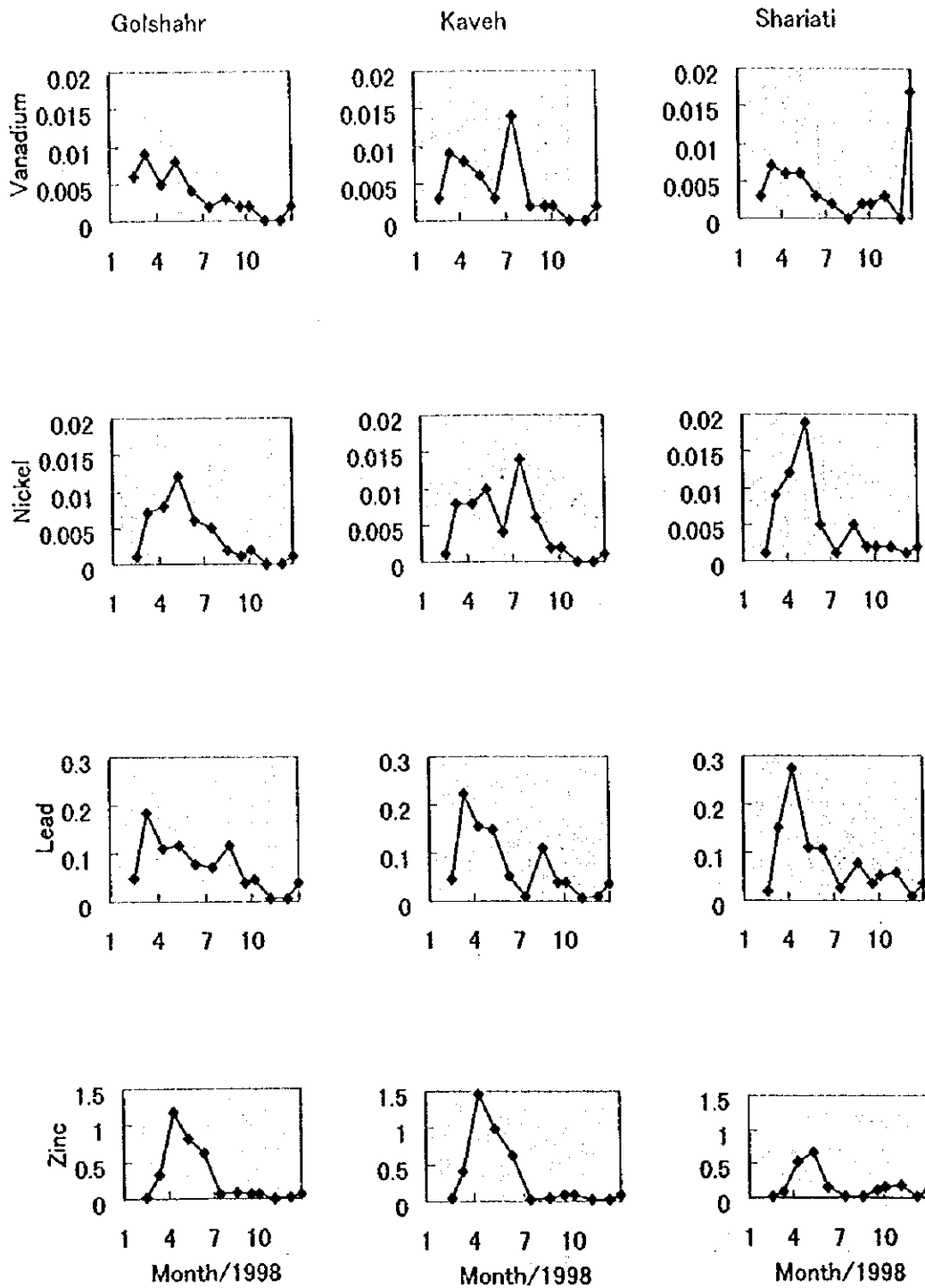
Fig. 9.2.2   Annual Metal Concentration Trends in Air of Esfahan

(Unit: $\mu g/m^3$ vs. Month in 1998)

B) Settled Dust

Original analytical data are listed in Appendix 6-5. The ranges of metals in settled dust are given in Table 9.2.3 out of samples collected from February to December 1998.

Mayan and Qaramalek stations had respectively three and two incidents of abnormally high zinc contents, which were supposed to be effected by entering tips of artificial material such as paint-peels into the deposit gage by strong wind.

Table 9.2.3   Metals in Settled Dust

| Monitoring Station		V	Ni	Pb	Zn
Tabriz	Baranloo	0.01 - 1.41	0.03 - 1.10	0.02 - 1.08	0.5 - 32
	Mayan	0.01 - 0.47	0.02 - 0.97	0.03 - 3.55	0.4 - 801
	Qaramalek	0.01 - 0.34	0.02 - 0.70	0.30 - 2.26	0.5 - 132
Esfahan	Golshahr	0.01 - 0.53	0.01 - 0.35	0.12 - 1.39	0.1 - 16
	Kaveh	0.00 - 0.30	0.02 - 0.41	0.02 - 1.35	0.5 - 12
	Shariati	0.02 - 0.57	0.10 - 0.50	0.11 - 3.25	0.4 - 16

Unit: mg/kg (or μ gram/gram)

The minimum Pb contents was obtained in February when there was less traffic of cars because of snow and in summer when atmosphere was favorable to dispersion because of the unstable condition. As V and Ni contents are in the similar range respectively in Tabriz and Esfahan, it can be said that majority of the metals come from the same source. And the source will be soil. The contents of V and Ni in settled dust are in the same order with those in SPM. The Clarke Number may not be representative of the Iranian soil.

Fig. 9.2.3 and 9.2.4 illustrate annual trends of metal concentrations in airborne particulates: SPM (◆dots) and settled dust (■dots). In Esfahan, the metal concentrations show almost identical trends in both SPM and settled dust in one year. However, in Tabriz, the trends are different from each other except those of Vanadium.
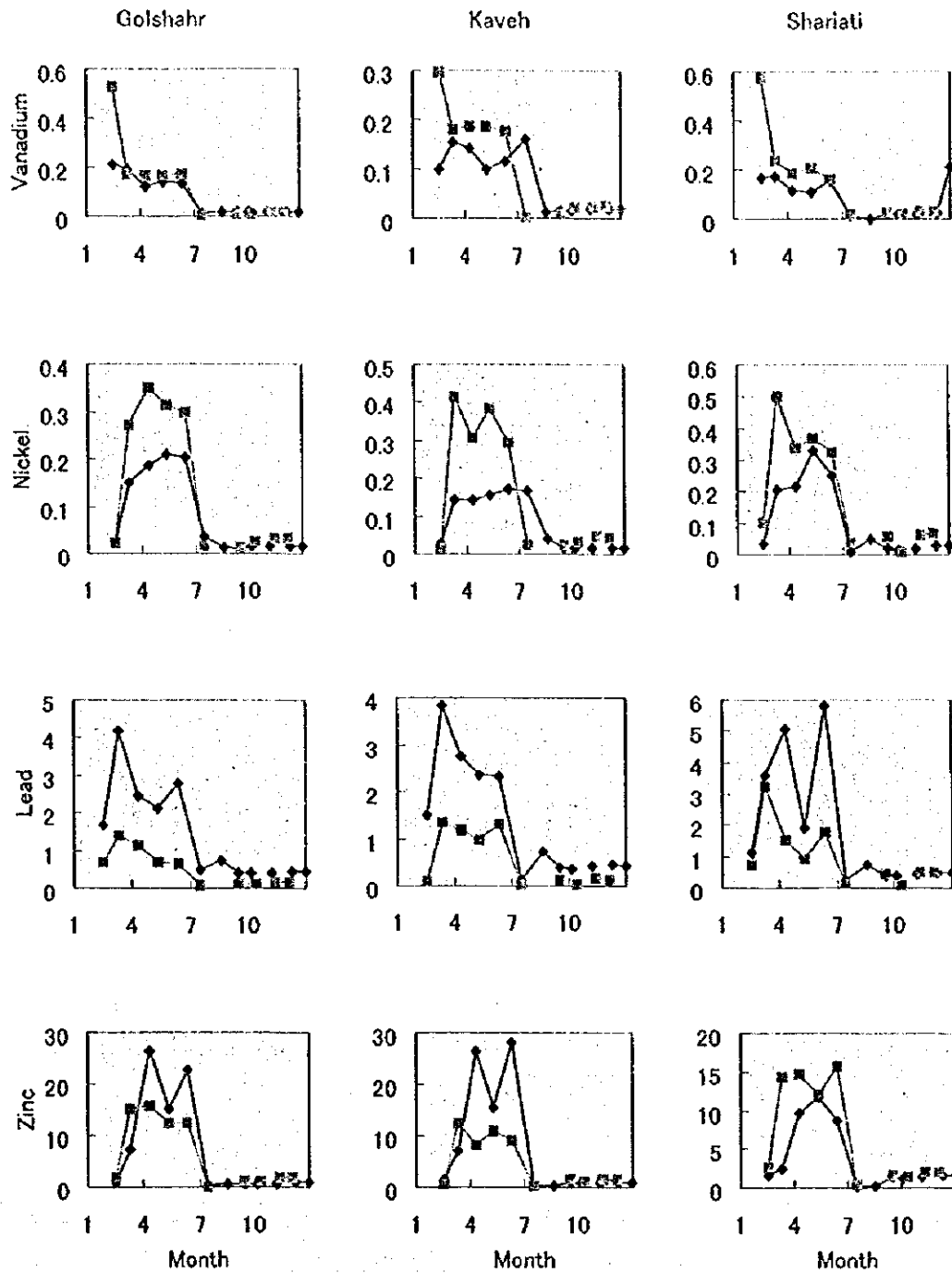
C) Soot

Table 9.2.4 shows analytical data of metals in soot of stack gases at Tabriz and Esfahan. The shaded data in the table are metal analyses in soot grabbed from heaps in the skirt bottom of the stacks at Tabriz and Esfahan for reference.
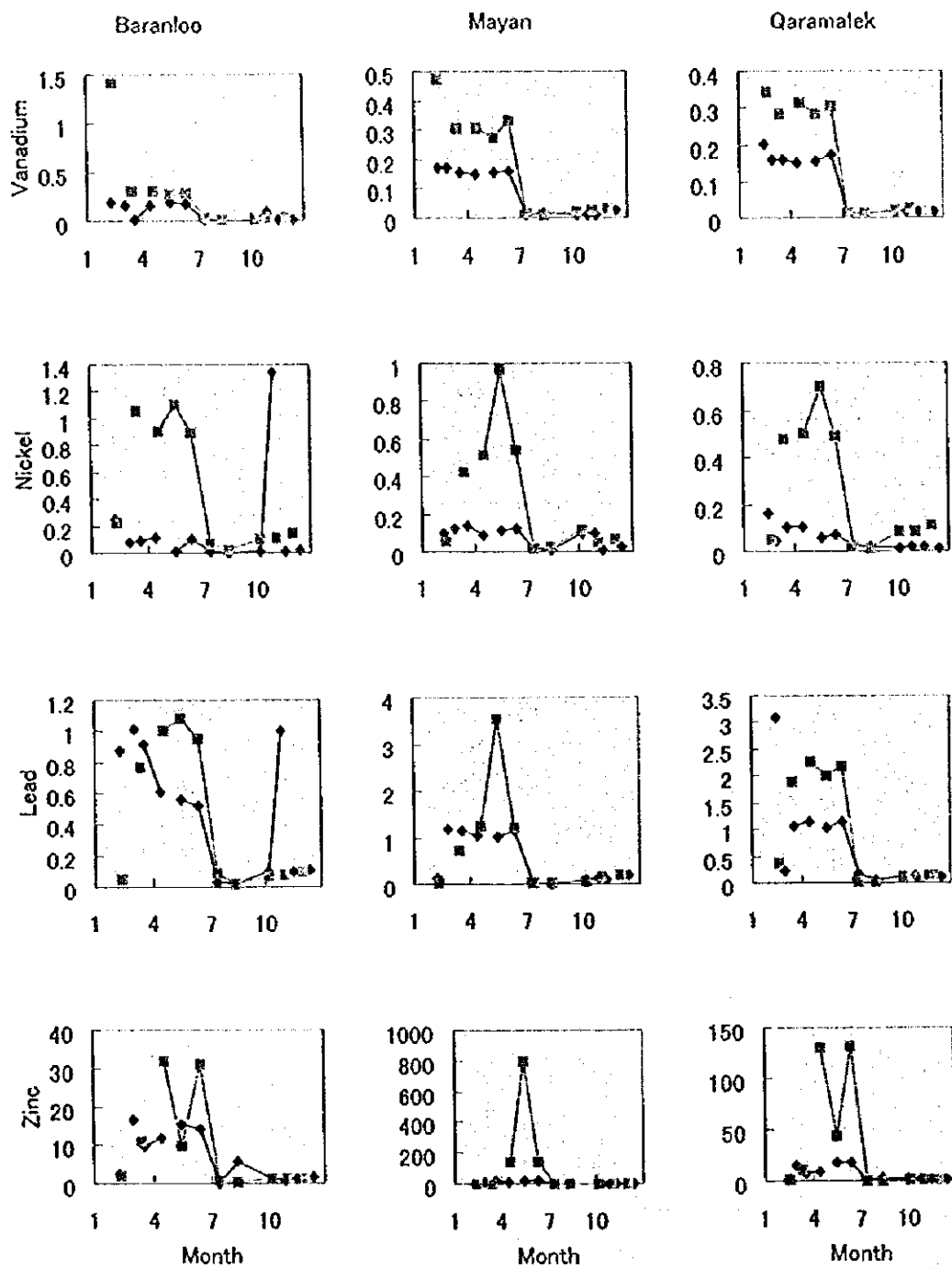
Unit: Metals in μg/gram of particulate (■Settled Dust and ◆SPM)

Fig. 9.2.3   Annual Metals in Airborne Particulate in Tabriz

Unit: Metals in μg/gram of particulate (■ Settled Dust and ◆ SPM)

Fig. 9.2.4   Annual Metals in Airborne Particulate in Esfahan

Table 9.2.4   Metals in Soot

Boiler	V	Ni	Pb	Zn	Remarks
Tabriz No.1	0.31~1.98	4.32~33.5	0.03~1.65	0.13~99.6	
Tabriz No.2	2.03	36.5	1.88	101.6	
EsfahanNo.3	0.29~0.47	7.14~18.33	0.04~1.41	3.14~96.9	
Esfahan No.4	0.36~0.93	4.64~12.77	0.08~1.54	2.00~80.25	
Esfahan No.5	0.16~0.27	1.91~11.77	0.92~1.12	52.80~73.2	
Tabriz No.1	5.43	60.00	0.64	1.67	Grab at the stack
Esfahan No.4	7.50	74.10	0.73	4.92	ground bottom

Unit: mg/kg of soot

As in Table 3.2.3, the ratio of V and Ni is 2 to 5. On the contrary, the ratio is far less in soot. Soot or ash in the boiler, the economizer, or the air-heater may have higher V contents. However, it was not true from the analytical results of the grab samples. Difference of oil will be the reasonable answer to this issue.

Table 9.2.5   Metals in Stack Gas

Boiler	Soot	Metals in Stack Gas (mg/m^3)			
	mg/m^3	V	Ni	Pb	Zn
Tabriz No.1	210	0.0004	0.007	0.0003	0.021
Esfahan No.3	470	0.0002	0.008	0.0007	0.045
Esfahan No.4	740	0.0007	0.009	0.001	0.59
Esfahan No.5	140	0.0000	0.002	0.0002	0.01
DMEG (#108) mg/m^3		0.5	0.015	0.15	4.0

Table 9.2.5 was prepared from the maximum soot load given in Table 7.2.9 and the maximum contents of each metal in Table 9.2.4, in order to compare with the values proposed by U.S.EPA as DMEG (Discharge Multimedia Environmental Goal) which are emission level goals (#108). All metals analyzed are under the goal values.

D)   Contribution of Soot to Air Borne Particulate

Table 9.2.6 is metal compositions in percentile of SPM, settled dust, and soot of the lower and higher limits in Tables 9.2.1, 9.2.3, and 9.2.4 individually.

Air borne particulates such as SPM and settled dust consist of ones emitted from natural and artificial origins: such as soil by wind blow, processing in factories (crushing, conveying, storage), combustion of fuel (factories and automobiles), attrition of solid materials, etc. Metal contents in the air borne particulates are the results of amounts and compositions of particulates from each emission source. Table 9.2.6 confirms that the power plant is not the only source of the particulate emission, because of the large

differences of Ni and Pb contents between soot and airborne particulates.

Table 9.2.6 Metal Percentiles in Particulates

Area	Particulates	V %	Ni %	Pb %	Zn %
Tabriz	SPM	0.8 - 3.8	2.5 - 3.8	7.9 - 20.5	71.8 - 88.7
	Settled Dust	0.2 - 1.6	0.3 - 3.8	0.7 - 18.9	91.2 - 98.8
	Soot	1.4 - 1.6	25.1 - 27.8	1.3 - 1.3	69.3 - 72.2
Esfahan	SPM	0.7 - 1.8	0.9 - 2.5	17.0 - 47.2	48.5 - 81.4
	Settled Dust	2.1 - 2.7	2.4 - 9.2	11.4 - 17.7	70.9 - 83.6
	Soot	0.6 - 1.1	14.3 - 18.6	1.4 - 1.4	78.9 - 83.7

It is impossible to estimate contribution of soot to SPM and settled dust formation by analyzing only 4 kinds of metals.

E) Gaseous Pollutants

Appendix 9-6 lists all the original data of chemical analyses of passive samplers carried out for four times from February to November 1998, together with maps of both target areas plotted with numbers of sampled sites. The number of passive samplers is variable in each occasion because of missing on recovery or shortage of manpower for placing.

The Tabriz plant site has higher SO_2 concentration generally among others. This may be resulted by down wash effects of stacks or leakage of gases from the plant equipment. The place near the refinery showed the highest SO_2 concentration in winter. There were no more SO_2 built up in the place in other seasons. One spot inside of Tabriz City has the second highest SO_2 concentration which may be caused by the diesel emission or by a domestic chimney. Higher SO_2 concentration is observed in vicinity of petroleum complex in Tabriz.

The Esfahan plant site has the highest SO_2 concentration in Esfahan, although the data is far lower than the ones in Tabriz.

The passive samplers could not identify any feature of SO_2 in Qa-e-Mieh. In autumn, at the east end of Qa-e-Mieh, the highest indication of NOx and NO_2 was obtained. This part is about 10 km from the center of Esfahan and in the narrow gap of two hills routed by the busy road. NO_2 generated by sunshine from NO in the city and NO from the road probably caused this high concentration at the gap. Other two places in Qa-e-Mieh also indicated rather high NOx in autumn.

Appendix 9-7 is a list of data of passive samplers and automated analyzers and their comparison is illustrated in Fig. 9.2.5 which has a dotted line showing equal values of both passive and automated data. The passive data of Esfahan are all below the dotted line indicating that all values of the data are lower than those of the automated data. This was

supposed that Esfahan had encountered difficulties of passive sampler storage, placement, or else. Regression by showing a straight line in Fig. 9.2.5 is better of NO₂ and NOx than of SO₂ in both regions.

The passive method has its limit of application, because of difficulty of absorbing very diluted pollutants in the air, keeping consistent paper quality, escaping from contamination during impregnation, storage and transportation of filter paper, mishandling of site locations, avoiding making analytical errors, etc. The sampling has to be applied by knowing its low sensitivity and unavoidable variation of data. Data taken by the passive method should not be directly compared with the data of the hourly, daily, or annual averaged values given in the Iranian ambient standards or WHO guidelines. However, it is worth to find localized tendency of air quality in the surrounding area.
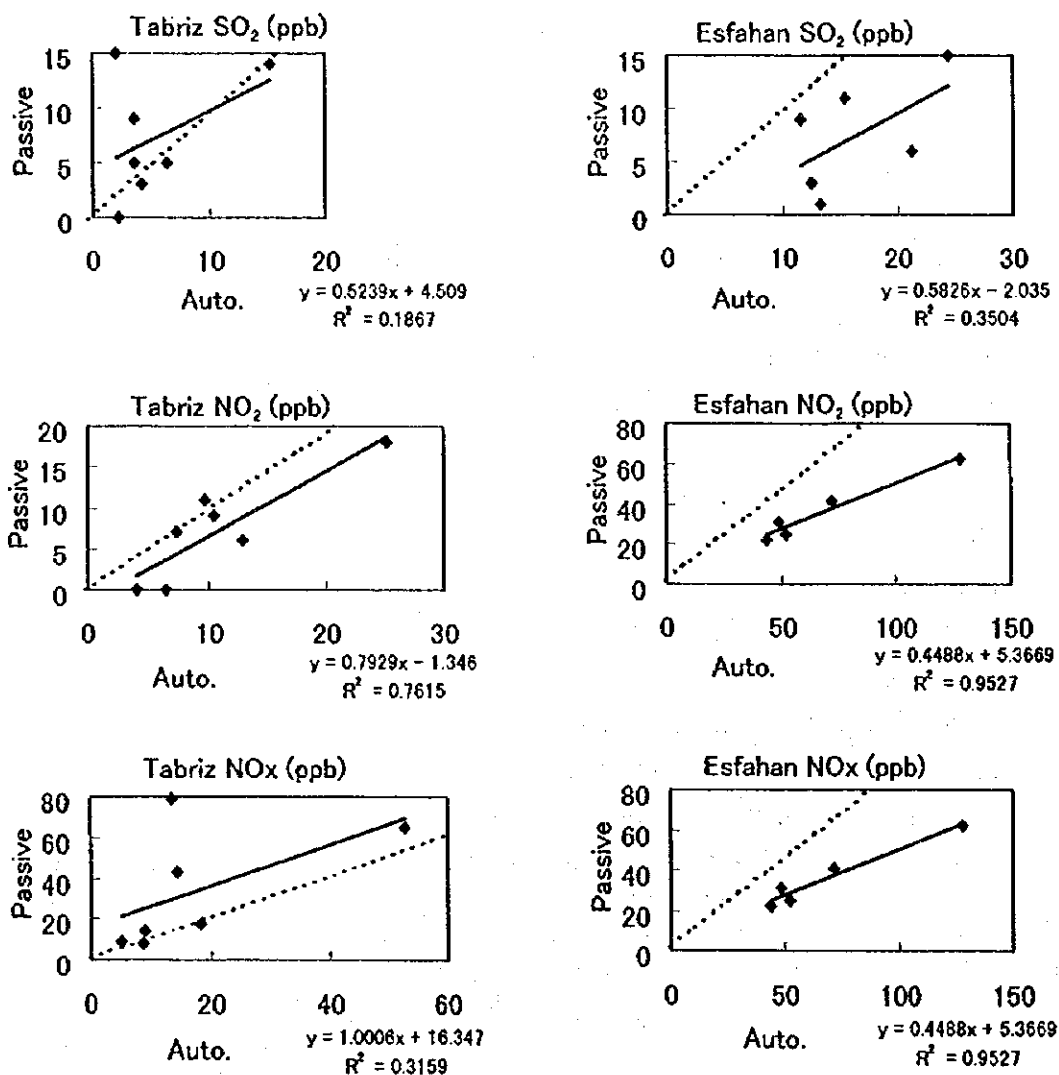

Fig. 9.2.5   Comparison of Passive and Automated Monitoring Data