

HAZARDOUS AIR POLLUTANT SOURCE EMISSIONS FOR A CHEMICAL FIBER MANUFACTURING FACILITY IN TAIWAN

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Abstract. The chemical and fiber industries in Taiwan are very important contributors to economic development of Taiwan over the past several decades, but it often associated with serious air pollution problems. The study was initiated in response to odor complaints from residents of neighborhoods located adjacent to the largest chemical fiber manufacturing plant in Taiwan. The purposes of this article are: (1) to characterize the source emissions; (2) to quantify some odorous components and VOCs in the ambient air around the plant; and (3) to compare measured ambient concentrations of emitted compounds with Taiwan's guidelines for Hazardous Air Pollutant (HAP) ambient concentrations. Gas samples were analyzed for target sulfurous and volatile organic compounds, e.g., sulfides, mercaptans, BTX, etc. Ambient samples were collected using Tenax adsorbent tubes for mass spectrometric analysis. On-site sampling and analysis was also conducted for SO₂ by Continuous Emission Monitoring (CEM). The resulting measured ambient air concentrations were compared to published odor threshold limits and Taiwan's regulatory standards for hazardous air pollutants. Subsequently, a Gaussian dispersion model incorporating the measured data was applied to estimate the source emissions and provide advance warning to the affected neighborhoods. The factors controlling formation of the odors at the facility and in the residential neighborhoods were identified. Additionally, environmental conditions (wind speed and wind direction) that could affect concentrations of emission constituents were discussed.

Keywords: chemical fiber industries, odor, sulfurous compounds, volatile organic compounds

1. Introduction

Due to geographical restrictions, Taiwan (area: ~36 000 km²; pop.: ~22 000 000) is short of natural resources. Over the past 20 yr, the discarded branches and twigs from logging yard have been left in the forest to rot, wasting a valuable resource for production. For this reason, the Formosa Chemicals and Fiber Corporation Changhua Plant (FCFCCP) was established in 1965, and used tree branches and hardwood to produce stable rayon fiber, nylon filament and nylon stretch yarn. Although this industry has been declining during the recent decades in Western countries, it is still very extensive in Asia and in Eastern Europe (Rigterinck, 1988). For example, the Fiber Economics Bureau reported that the rayon fiber production in the year of 1998 is 1213×10^3 metric ton in Asia, 674.4×10^3 metric ton in Europe, and 393.1×10^3 metric ton in North America (Fiber Economics Bureau, 1999). In the process of rayon production involved carbon disulfide (CS₂) is used



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to dissolve cellulose, and during the regeneration of cellulose CS_2 and H_2S are released into atmosphere. These chemicals are toxic and pose a major environmental problem (Wolschner *et al.*, 1995). Due to their very low odor threshold value, high toxicity, the presence of volatile sulfur compounds in waste gases deserves special attention (Mukherjee *et al.*, 1989).

The Changhwa Plant operates one of the largest chemical and fiber plants in Taiwan with the amount of rayon production of 161×10^3 metric ton yr^{-1} (Lei, 2000). This site, which is close to residential areas, is a major contributor to the economic development of central Taiwan, providing nearly 5000 job opportunities. For a long period of time, this site presented an odor problem and adversely impacted the air quality in areas adjacent to the chemical plant. Results from a questionnaire survey show that the closer you lived to FCFCCP, the more you detected an odor (Lin and Lin, 2000). In addition to the odor problem, it was estimated that FCFCCP emitted 2283 tons yr^{-1} of SO_x and 71 tons yr^{-1} of VOCs. Therefore, FCFCCP is thought to be one of the major pollutant emitters in Changhwa county (Gee-lei, 1997).

Since 1995 there have been increasing public protests from citizens who believe that the emissions of sulfurous and volatile organic compounds are harming their health. According to the petition, many of these people detect odors and experience unpleasant symptoms, and attribute them to the emissions from FCFCCP (Bureau of Environmental Protection, 1997). Because of the increased public attention to nuisance odors, an assessment of odors in the residential vicinity of FCFCCP was desired for quantifying the odors. The objectives of this study are to monitor some specific Hazardous Air Pollutants (HAPs) in the ambient air around the FCFCC area and to characterize the distinct and potential odorous compounds. These HAPs are believed to be associated with the source emissions from FCFCCP, such as carbon disulfide, hydrogen sulfide, dimethyl sulfide, chloroform, MEK, and BTX, etc. These compounds were analyzed and quantified during the sampling portion of this study. The resulting measured ambient air concentrations were compared to published odor threshold limits and Taiwan's regulatory standards for hazardous air pollutants. It is believed that the study is of value to other air pollution researchers, and it can be generalized to other major rayon fiber manufacturing countries, e.g. China, India, and Indonesia in Asia, C.I.S. in Eastern Europe, and U.S.A. in North America.

2. Methodologies

2.1. AREA DESCRIPTION

In the area studied, the prevailing wind directions vary with the season, with normally north and northwest winds. The annual average wind speed is about 1.7 m s^{-1} . The highest monthly average wind speed appears in January and February with

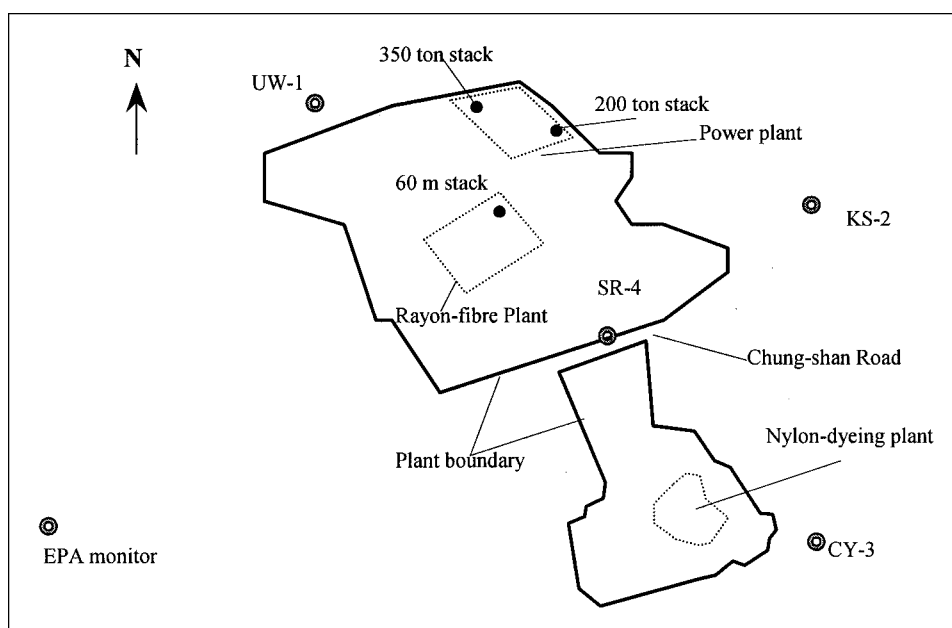


Figure 1. Map of the study region showing the location of sampling sites relative to the FCFC Changhwa Plant.

a magnitude of 2 m s^{-1} . In contrast, the lowest average, 1.4 m s^{-1} , occurs in May and August.

The FCFCCP (ca. 70 ha) includes three major plants (i.e., Rayon-fibre Plant, Power Plant, and Nylon-dyeing Plant) are located in the northeastern corner of Changhwa County, Taiwan, and in the central area of the residential community of Changhwa city (area: $\sim 66 \text{ km}^2$; pop.: $\sim 220\,000$). According to the data recorded by Changhwa EPA, there are two major sources (sulfurous compounds and VOCs) produced by the three plants. The Rayon-fiber Plant, which emits sulfurous compounds, and the Power Plant, which emits primarily SO_2 , are both located in north of the city (North plant). However, the Nylon-dyeing Plant, which emits potential VOCs, is located south of the city (South plant). The North and South plants are separated by Chung-Shan road as shown in Figure 1.

Based upon previous studies and process activities in the chemical plant, SO_2 is produced by two power plant stacks (produced 350 and 200 tons of water vapor hr^{-1} by coal-fired boilers) at the Power Plant. Sulfurous compounds are emitted by one 60-m stack at the Rayon-fiber Plant for point source emissions. However, the fugitive sources, including sulfurous compounds and VOCs, are usually present at both the Rayon-fiber and Nylon-dyeing Plants (Lin, 1998).

2.2. SAMPLING SITES AND SCHEDULE

Sampling locations were selected to include all of the major foul air sources around the target plant. These would typically include: one sampling location upwind (UW-1); two sampling locations downwind (CY-3 and SR-4); and one sampling location (i.e., KS-2) between the boundary dividing the Rayon-fiber and Nylon-dyeing Plants. The sampling sites are shown in Figure 1. Based on the previous weather conditions (primarily N or NNW winds), the location of the sampling sites was arranged as follows: (1) UW-1 served as a monitoring station to measure the background concentrations. (2) KS-2, located east of the two power plant stacks, served as a monitoring station to measure the relative SO₂ concentration contributed either by the two power plant stacks or other source emissions. (3) SR-4, located downwind of the Rayon Plant, served as a monitoring station to measure the concentrations of sulfurous compounds. (4) CY-3, located downwind of the Nylon-dyeing Plant, served as a monitoring station to measure the concentrations of VOCs.

The monitoring program included the measurement of ambient sulfur and VOC concentrations, and the installation of a Continuous Emission Monitoring system (CEM) for SO₂. For the ambient sulfur and VOC measurements, air samples were taken at the breathing-zone level at every sampling station, using Tenax-TA adsorbent tubes through a low flow sampler pump. Two-hour adsorbent samples in triplicates at four sampling sites were taken for laboratory analysis on seven intervals from March 28 to March 30. The sampling program, with seven intervals was: 18:00–20:00 (March 28), 2:00–4:00 (March 29), 10:00–12:00 (March 29), 18:00–20:00 (March 29), 00:00–2:00 (March 30), 6:00–8:00 (March 30), and 13:00–15:00 (March 30). For the continuous SO₂ monitoring, the monitoring program consisted of simultaneous and continuous wind direction and velocity measurements along with continuous SO₂ monitoring at 2 locations (i.e., UW-1 and KS-2 sites). These measurements were made at the sites over a three-day period (i.e., March 28–30).

2.3. SAMPLING METHODS

Sulfurous compounds and VOCs were collected using Tenax-TA adsorbent tubes. The sampling procedure is based on EPA Method TO-1 (EPA, 1984). SO₂ emissions were measured with the aid of two continuous emission monitors. Wind direction and speed measurements were made using two weather monitors. The signals from the SO₂ analyzers and weather monitors were recorded simultaneously using a data acquisition system. The following provides a description of each of the various components in the emission sampling system.

2.3.1. *Sulfurous Compounds and VOCs Measurement*

The Tenax-TA adsorbent tubes were incorporated with a low flow sampler pump (Gilian Model 113). The sampling rate at each location was periodically checked and adjusted with a Gilian Air Flow Calibrator.

2.3.2. *SO₂ Measurement*

Ambient SO₂ concentrations were measured on-site using two Model 4108 Fluorescence SO₂ Analyzers (Dasibi, Inc.), one placed upwind and the other in the downwind location of the North Plant. The SO₂ monitor was operated continuously on a 0–500 ppb range. Data were recorded using a data acquisition system.

2.3.3. *Wind Direction and Speed Measurements*

Measurements were determined with the aid of two weather monitors (Davis Instruments Weather Monitor II) which were pre-calibrated. The monitors were located along side the SO₂ sampling points and represented the wind direction and speed for the upwind and downwind zones.

2.4. ANALYTICAL METHOD

Air samples were collected using Tenax-TA adsorbent tubes through a low flow sampler pump at every sampling station. Each sample was analyzed for the following:

2.4.1. *Sulfurous Compounds*

The adsorbent tube samples were analyzed for sulfurous compounds, using high resolution capillary gas chromatography with a flame photometric detector (Chrompack CP 4010; GC/FPD). The GC/FPD unit was equipped with a standard Thermal Desorption Cold Trap injector and a fused silica capillary column (Chrompack CP-Sil 8 CB, 30 m long, 0.32 mm I.D., 0.25 μm film). The initial GC operating temperature was 50 °C for 1 min. The temperature program (temperature rate, final temperature, holding time) was: 8 °C min⁻¹, 120 °C, 3 min.

2.4.2. *VOCs*

VOC samples collected were analyzed with the EPA Method TO-1. The Hewlett-Packard GC unit (HP G1800A GCD system) was equipped with a Thermal Desorption and Cold Temperature injector (Chrompack CP 4020 TCT) and a Chrompack CP-Sil fused silica capillary column, 50 m long × 0.32 mm inner-diameter with a 1.2 μm film thickness). The oven temperature program was: 40 °C for 2 min initially with a 5 °C min⁻¹ ramp to 200 °C. Temperature settings for the Thermal Desorption Cold Trap are: -130 °C, cold trap; 250 °C desorption; and a 200 °C heating of the cold trap for injection.

2.4.3. *Ambient SO₂*

Air samples were drawn through a filter, to remove particulate matter, and into an inverted funnel which was attached to Teflon tubing. Prior to entering the analyzer, the sample was passed through a permeation dryer to remove any water in the sample. The detection limit and the precision of the SO₂ Analyzer were 1 ppb. The CEM systems were periodically zeroed and spanned at the inlet locations as

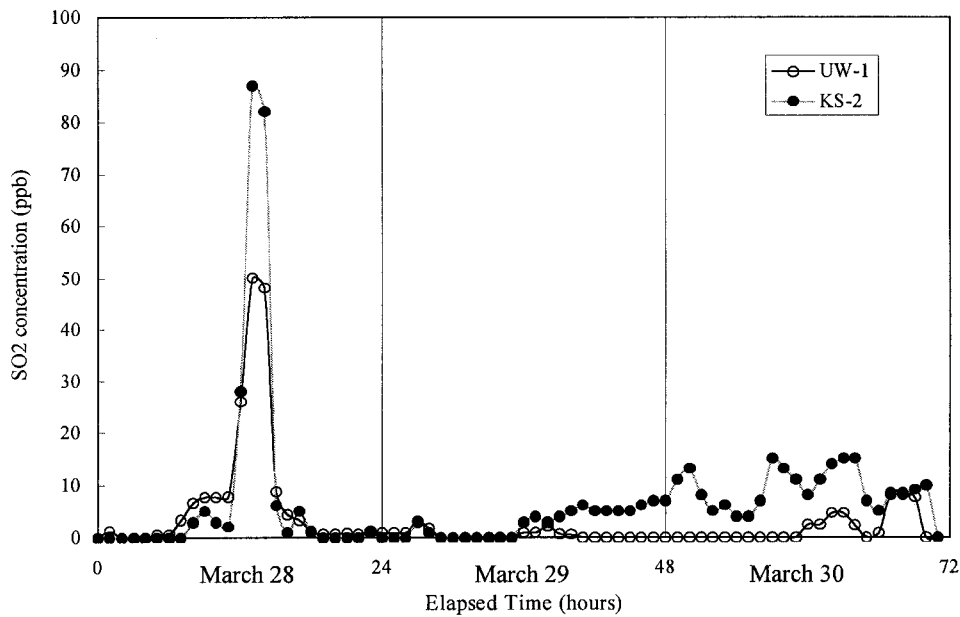


Figure 2. SO₂ concentrations observed for the period from March 28–30 sampling campaigns.

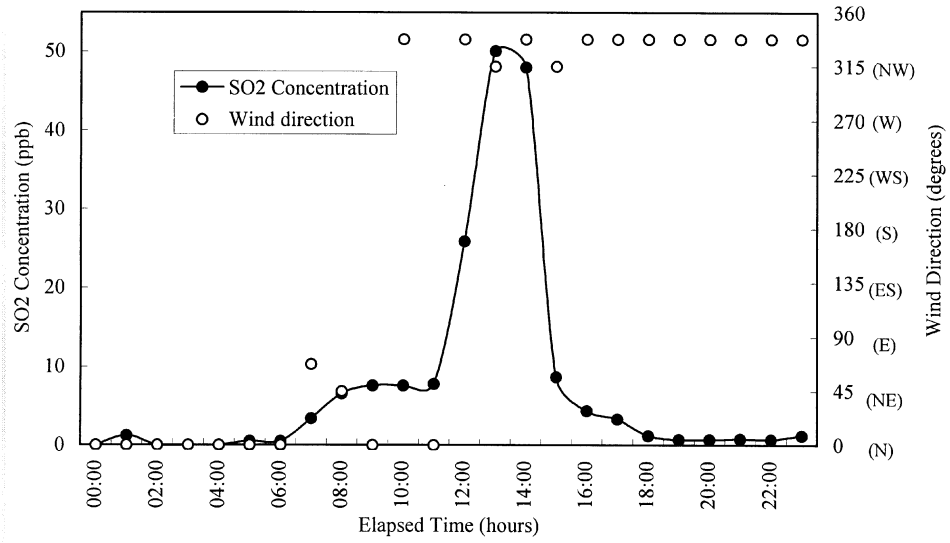
well as at the analyzers using a SO₂ calibrator (SABIO Model 2000SA). Zero air (nitrogen) and span gases were introduced and the output recorded using the data acquisition system. With respect to SO₂ span gas, 49.9 ppm gas was used to calibrate the system.

3. Results and Discussion

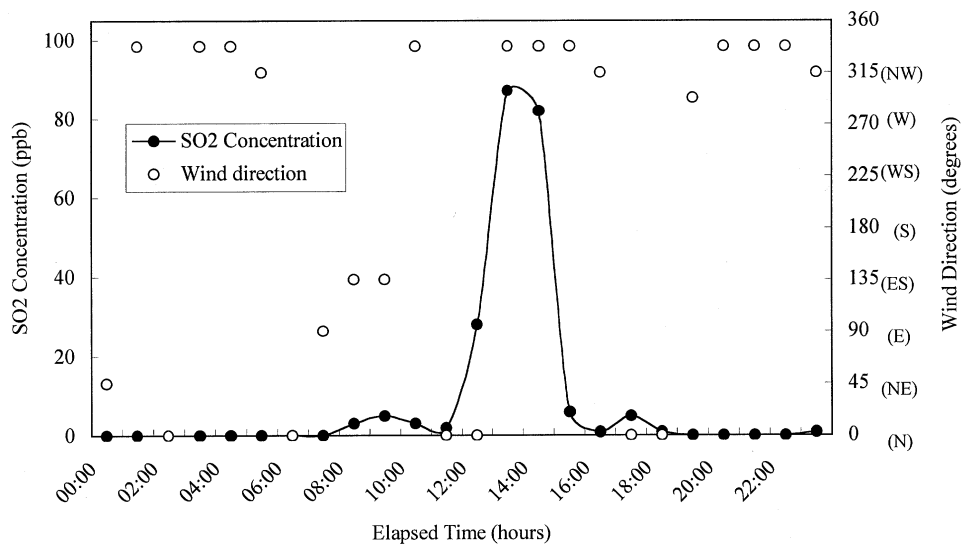
3.1. SO₂ CONCENTRATIONS

The hourly variation of SO₂ emissions is presented in Figure 2. SO₂ concentrations measured from the UW-1 sampling station are generally constant at about 0–8.7 ppb with the exception of 28 March between 12:00 and 15:00 when the concentration reached a maximum of 50 ppb. Similarly, the SO₂ concentrations at KS-2, which did not seem to have any temporal or diurnal variation, and were generally constant at about 0–15 ppb with the exception of 28 March between 12:00 and 15:00, when the concentration reached a maximum of 87 ppb. The peak concentration observed at both the sampling stations, is believed to be due to other emission sources instead of FCFCCP (will be discussed later).

Figure 3 is a plot of the SO₂ concentration at the UW-1 and KS-2 monitoring sites versus the direction of wind on March 28. As can be seen, most of the winds at UW-1 were from the N in the morning hours or NNW and NW in the afternoon hours, and most of the winds at KS-2 were from the NNW, NW, or



(a) UW-1



(b) KS-2

Figure 3. SO₂ concentrations and wind direction versus elapsed time at UW-1 and KS-2 monitors on March 28.

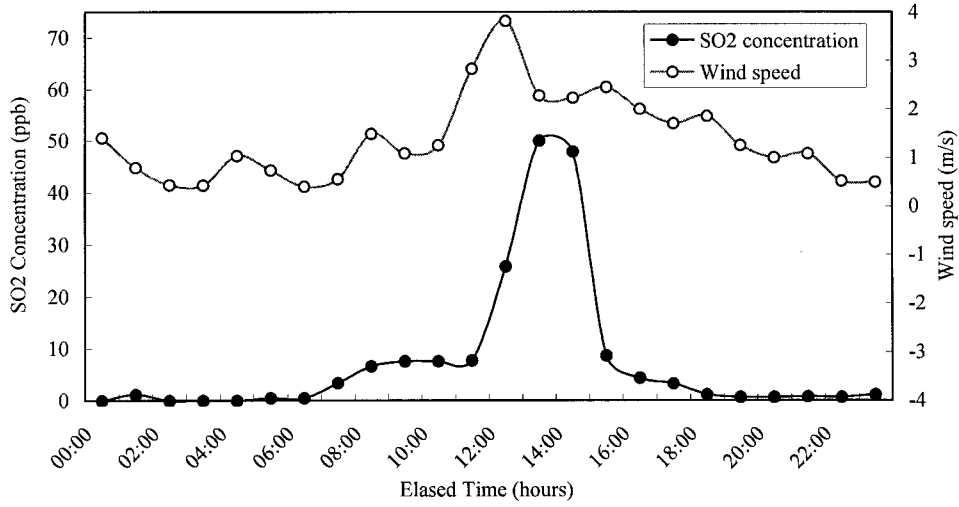
N. Therefore, UW-1 must be in the upwind zone and KS-2 was closed to the downwind zone. Peak concentrations were detected at UW-1 and KS-2, i.e., 50 and 87 ppb. Although peak concentrations observed at KS-2 were higher than the upwind concentrations (i.e., UW-1), it is hard to conclude that those increments are contributed by FCFCCP because an upwind source that has a wide plume and closer to the centerline at KS-2 than at UW-1 is possible.

Figure 4 is a scatter plot of the SO₂ concentration and wind speed during the sampling period on March 28, and shows the correlation between wind speed with pollutant concentration. In general, data recorded at UW-1 showed some dependence upon wind speed (Figure 4a); however, data recorded at KS-2 showed a strong dependence upon wind speed (Figure 4b). In other words, the measured SO₂ concentration increases with the wind speed.

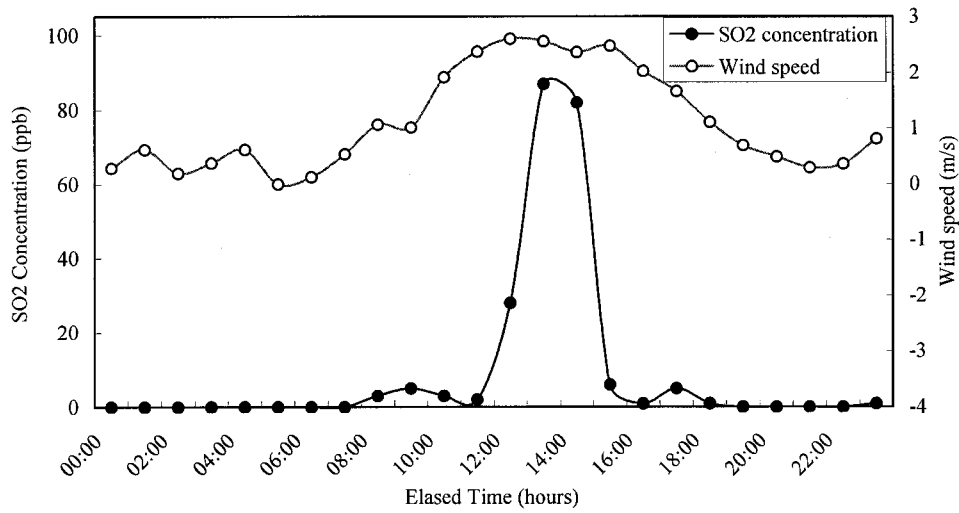
It was interesting to know why the elevated value was found at the upwind zone of UW-1 at 12:00–15:00 on March 28. We postulated that there were other emission sources besides FCFCCP based on the following reasons: (1) The wind speeds were somewhat higher and typically in the range of 2.2–3.8 m s⁻¹. Therefore, the pollutants could not be attributed to fugitive emission from FCFCCP. (2) The emission data for the two power plants were in the normal range (ca. 7 ppm) as shown in Figure 5. (3) According to the recorded data from the EPA's National Air Monitoring Station, located 2 km southwest of the FCFCCP, the wind directions were usually N, NNW or NW in January-March, 1998 (Figure 6). However, SO₂ concentrations measured from the EPA's station followed a similar trend as the concentrations detected at the UW-1 and KS-2 sites as shown in Figure 7. It was found that the SO₂ concentration was in the range between 2 to 20 ppb with the exception of 28 March between 12:00 and 15:00, when the concentration reached a maximum of 73 ppb. Based upon the above rationale, we concluded that a projected plume from the northwest could carry contaminants over the UW-1, KS-2, and EPA monitors, which caused the elevated SO₂ concentration. The Taiwan Coal-fired Power Plant (TCPT), emitting 200 000 tons yr⁻¹ of SO_x (Tu, 1997), located 50 km northwest of the FCFCC plant, was hypothesized as the potential source of SO₂.

3.2. SULFUROUS COMPOUNDS

A total of 28 air samples were taken from the sampling sites on March 28–30. Table I presents a summary of the range of concentrations of 4 sulfurous compounds at different sampling sites along with the average daytime and nighttime concentrations, their regulatory standards, and odor thresholds. It is evident that higher concentrations were measured at the downwind sampling site (i.e., CY-3) and surrounding sampling site (i.e., SR-4). In contrast, the UW-1 and KS-2 sampling sites show lower concentrations. Although KS-2 was situated close to the downwind side of UW-1, both were located upwind from the Rayon-fibre Plant, which was known to be a source of sulfurous compounds. Since no elevated con-



(a) UW-1



(b) KS-2

Figure 4. SO₂ concentrations and wind speed versus elapsed time at UW-1 and KS-2 monitors on March 28.

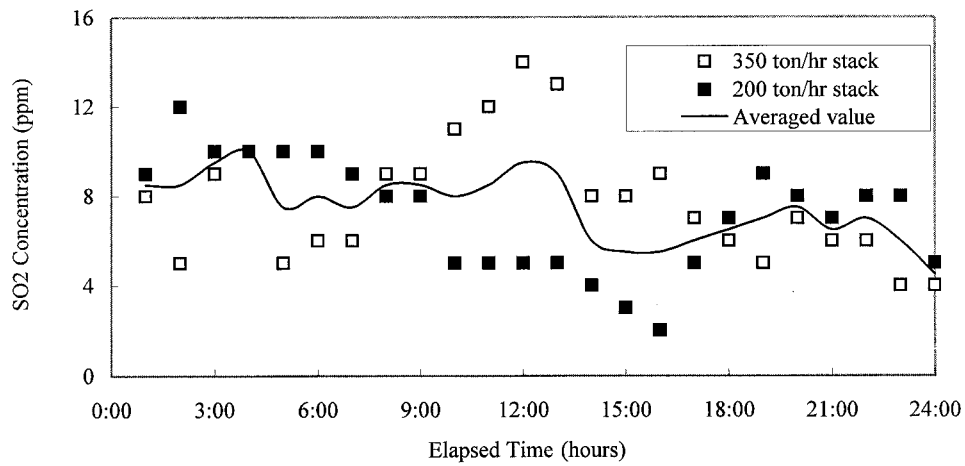


Figure 5. SO₂ concentrations measured at two power plant stacks on March 28.

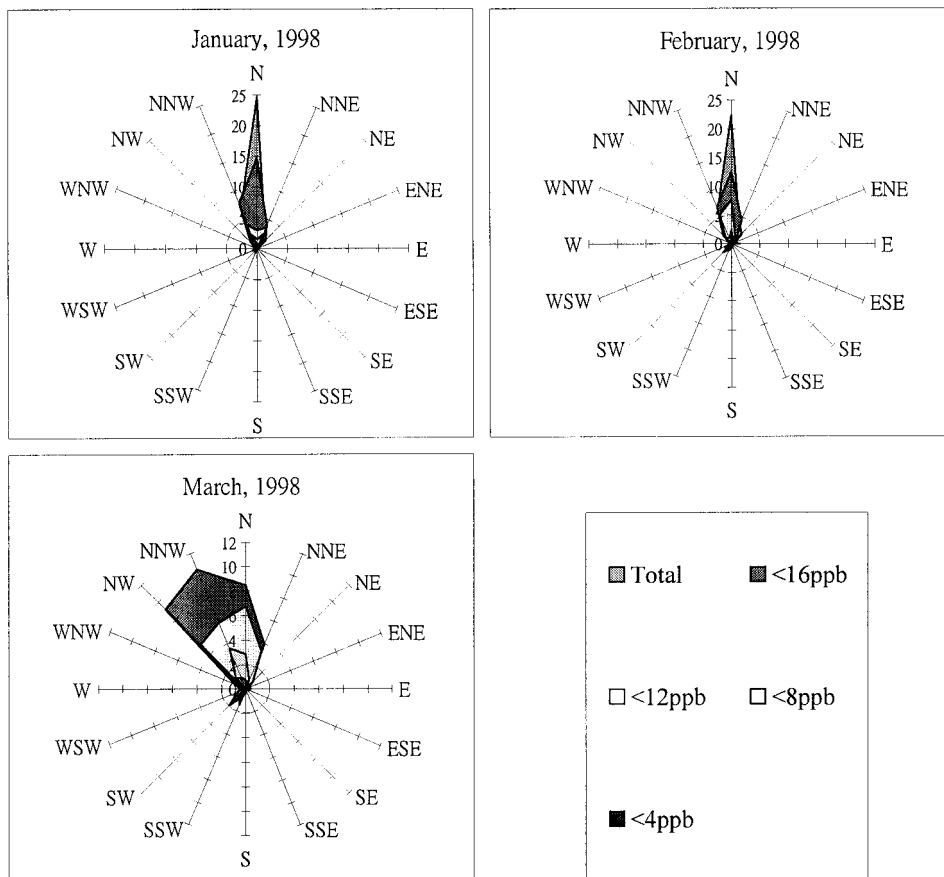
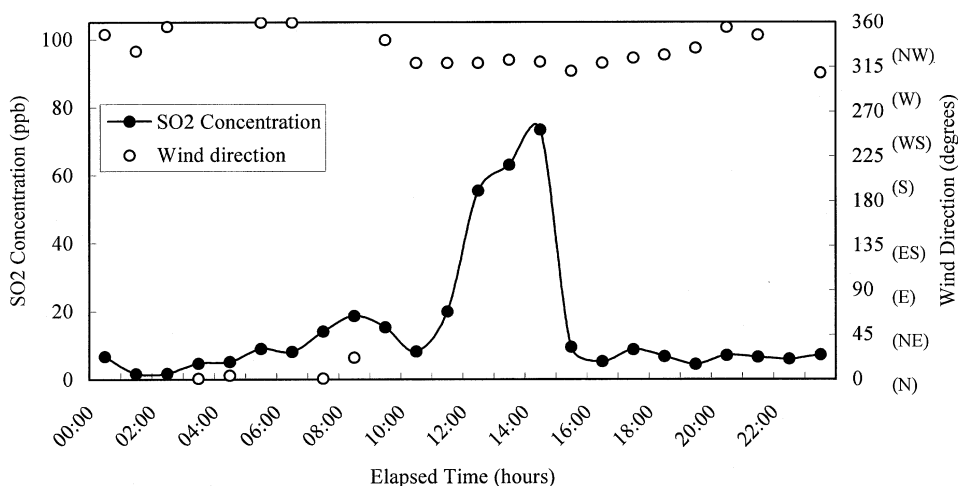
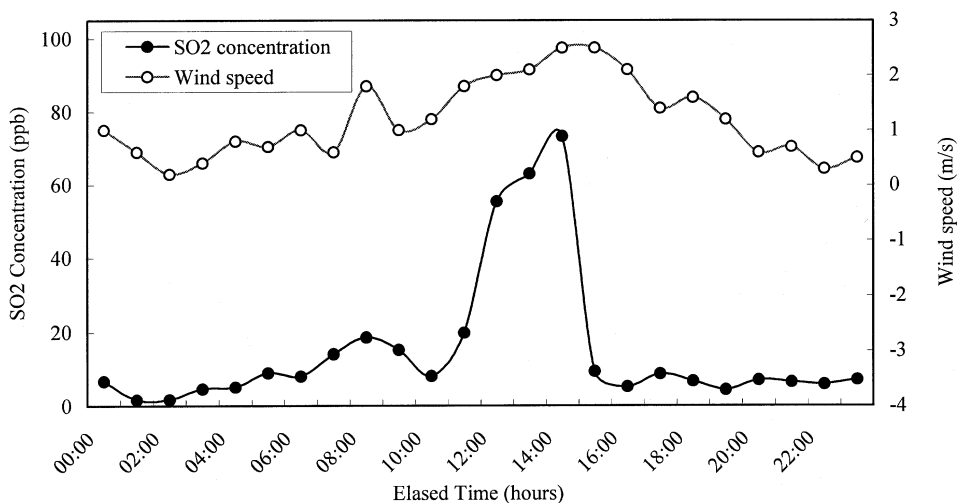


Figure 6. SO₂ concentration and wind direction at EPA monitor (data are for January–March 1998).

(a) SO₂ concentrations / wind direction .(b) SO₂ concentrations / wind speed.Figure 7. SO₂ concentrations and wind direction/wind speed at EPA monitor on March 28.

centrations of sulfurous compounds (other than SO₂) were observed for the UW-1 and KS-2 sites, it was concluded that a local source (e.g. FCFCCP) was responsible for these high concentrations at the CY-3 and SR-4 sites.

As seen in Table I, a diurnal pattern of the concentrations for the sulfurous compounds was not observed. However, total average ambient concentrations varied

TABLE I

Summary of the sulfur-related compounds measured at four sampling sites (data for regulatory standard and odor threshold are also shown)

Sampling site	Sulfurous compounds	Daytime		Nighttime		Overall		Total conc. range of all samples
		Mean	S.D.	Mean	S.D.	Mean	S.D.	
UW-1	H ₂ S	3.6	5.6	0.1	0.2	1.6	3.8	ND~10.1
	DMS	ND	ND	ND	ND	ND	ND	ND~ND
	CS ₂	1.0	0.2	0.7	0.5	0.9	0.4	ND~1.2
	2-C ₃ H ₇ SH	ND	ND	0.6	0.4	0.4	0.5	ND~0.9
KS-2	H ₂ S	0.8	1.4	1.9	2.2	1.4	1.8	ND~4.2
	DMS	ND	ND	ND	ND	ND	ND	ND~ND
	CS ₂	0.8	0.7	0.8	0.6	0.8	0.6	ND~0.4
	2-C ₃ H ₇ SH	ND	ND	0.2	0.5	0.1	0.3	ND~0.9
CY-3	H ₂ S	6.3	6.7	23.7	27.3	16.2	21.7	ND~61.7
	DMS	ND	ND	ND	ND	ND	ND	ND~ND
	CS ₂	9.1	11.8	3.6	4.0	6.0	7.9	ND~22.7
	2-C ₃ H ₇ SH	0.9	0.8	2.0	2.4	1.5	1.8	ND~5.4
SR-4	H ₂ S	6.3	7.7	14.7	17.7	11.1	14.0	ND~35.6
	DMS	5.3	9.1	ND	ND	2.3	6.0	ND~15.8
	CS ₂	31.7	45.7	70.6	124.2	53.9	94.0	ND~256.2
	2-C ₃ H ₇ SH	5.4	6.9	5.6	7.0	5.5	6.3	ND~15.8
		Regulatory standards		Odor threshold		Average concentration for 4 sampling sites		
		H ₂ S		0.47		7.6		
		DMS		-		0.6		
		CS ₂		210		15.4		
		2-C ₃ H ₇ SH		-		1.9		

S.D.: Standard deviation.

ND: Not detectable.

-: Data not available.

Unit: ppb.

with the different compounds investigated, and followed this order: CS₂ (15.4 ppb), H₂S (7.6 ppb), 2-C₃H₇SH (1.9 ppb), DMS (0.6 ppb). The results in Table I show that the chemical concentration of all samples met the regulatory standards, with a maximum concentration for CS₂ (256 ppb) observed at the SR-4 site during the nighttime sampling period. The comparison of H₂S concentration between measured data and odor threshold indicated that detected concentration had exceeded

TABLE II
Parameters used for predicting CS₂ emission rate

Parameter	Sampling sites	
	CY-3	SR-4
Measured concentration (ppb)	3.7	11.2
Downwind distance, X (m)	1018	213
Crosswind distance, Y (m)	46	130
Stability category	A	A
Wind direction	NNW	NNW
Wind speed (m s ⁻¹)	0.81	0.81
Horizontal dispersion coefficient, σ_y (m)	210	50
Vertical dispersion coefficient, σ_z (m)	400	40
Emission rate, Q (gCS ₂ s ⁻¹)	23.43	15.69

the odor threshold in several cases Leonardos *et al.*, 1969). This also was observed for CS₂ on some occasions. Because these compounds had lower odor threshold concentrations, the Bureau of Environmental Protection of Changhwa county still received some complaints, although the stationary stack emissions met the national standards (Bureau of Environmental Protection, 1997).

To roughly estimate the source emissions from the 60-m stack of the Rayon-fibre Plant, a back-calculation of the relevant parameters (see Table II) were entered into the Gaussian dispersion model and the measured data for CS₂ at CY-3 and SR-4 were used to estimate source strength. Modeling results indicated that the predicted CS₂ emission rates were 23.4 g s⁻¹ (from CY-3 data) and 15.7 g s⁻¹ (from SR-4 data). These estimated emission rates might be used to examine if the concentrations of sulfurous compounds will meet the regulatory requirements or odor thresholds in the future. Moreover, the predictive model might be used to provide advance warning to the affected community. However, it should be noted that the actual emission rates were required to be lower because the above calculation did not account for the fugitive emissions.

3.3. VOLATILE ORGANIC COMPOUNDS

A total of 28 air samples were collected from the sampling sites on March 28–30. Table III shows the VOC concentrations at 4 sampling sites for the daytime and nighttime average. With the exception of the UW-1 sampling site, the concentrations measured during the daytime hours were usually higher than the nighttime, as would be expected, since more activities occurred in the daytime hours (e.g. mobile sources). It should be noted that the UW-1 sampling site was located on the upwind side, and surrounded by farms; therefore, it was not expected to have

TABLE III

Summary of the VOCs measured at four sampling sites (data for regulatory standard and odor threshold are also shown)

Sampling site	VOCs	Daytime		Nighttime		Overall		Total conc. range of all samples
		Mean	S.D.	Mean	S.D.	Mean	S.D.	
UW-1	Benzene	ND	ND	18.3	16.9	10.5	15.5	ND~43.2
	Toluene	ND	ND	25.8	37.9	14.8	30.2	ND~81.7
	P-Xylene	ND	ND	11.7	14.3	6.7	11.9	ND~32.5
	Acetone	ND	ND	1.3	0.9	0.8	0.9	ND~4.5
	Chloroform	ND	ND	1.3	0.8	0.8	0.9	ND~2.4
	MEK	ND	ND	ND	ND	ND	ND	ND
KS-2	Benzene	37.4	18.3	17.0	16.8	25.8	15.5	ND~49.1
	Toluene	58.0	75.6	29.3	26.1	41.6	30.2	ND~145.2
	P-Xylene	22.1	36.8	15.1	14.3	18.1	11.9	ND~64.6
	Acetone	2.8	3.4	0.4	0.9	1.4	0.9	ND~6.5
	Chloroform	8.9	13.6	2.7	4.5	5.3	0.9	ND~24.6
	MEK	ND	ND	ND	ND	ND	ND	ND
CY-3	Benzene	6.4	3.9	8.9	9.7	7.8	7.3	ND~19.0
	Toluene	201.9	253.1	77.0	91.2	130.6	173.1	ND~489.6
	P-Xylene	11.3	6.2	17.6	20.9	14.9	15.6	ND~41.4
	Acetone	2.3	0.7	1.6	1.1	1.9	0.9	ND~3.1
	Chloroform	0.2	0.3	0.3	0.5	0.2	0.4	ND~1.1
	MEK	0.2	0.3	ND	ND	0.1	0.2	ND~0.5
SR-4	Benzene	14.3	13.0	6.8	8.9	10.0	10.6	ND~25.3
	Toluene	12.5	21.6	15.7	18.0	14.3	17.9	ND~40.7
	P-Xylene	9.8	9.8	5.5	5.4	7.3	7.2	ND~19.6
	Acetone	0.0	ND	2.2	1.9	1.3	1.8	ND~4.5
	Chloroform	4.5	7.7	2.7	3.7	3.4	5.3	ND~13.4
	MEK	4.5	7.7	0.7	1.5	2.3	5.0	ND~13.4
		Regulatory standards		Odor threshold		Average concentration for 4 sampling sites		
	Benzene	1595		172555		13.5		
	Toluene	7526		23657		50.3		
	P-Xylene	8671		9086		11.8		
	Acetone	-		236735		1.3		
	Chloroform	-		-		2.4		
	MEK	-		5878		0.6		

S.D.: Standard deviation.

ND: Not detectable.

-: Data not available.

Unit: $\mu\text{g m}^{-3}$.

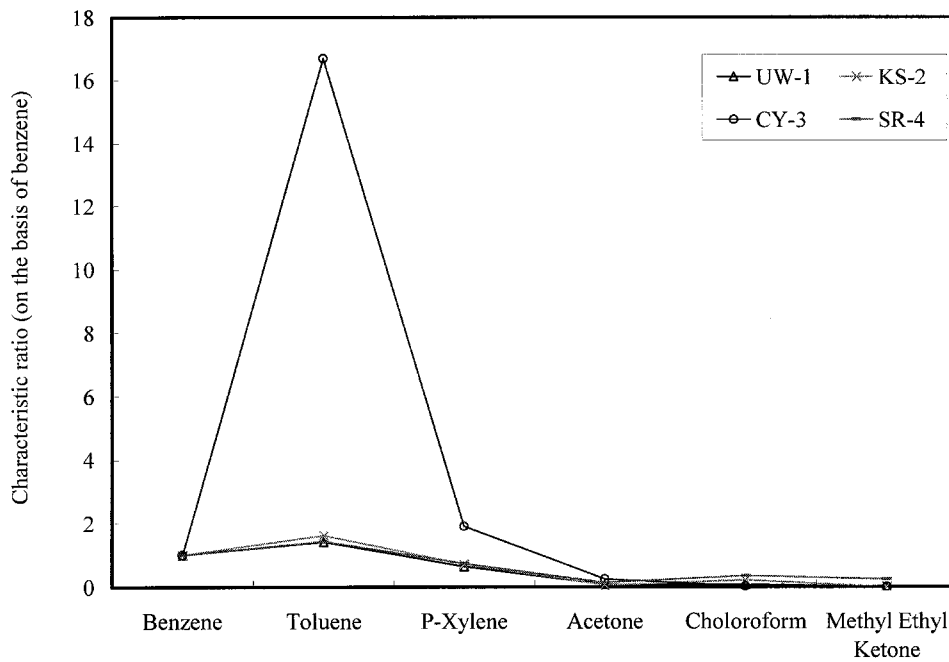


Figure 8. Characteristic ratio for VOCs at different sampling sites.

elevated VOC concentrations. Table III further shows that toluene, benzene, and xylene had higher concentrations (e.g. toluene of $489 \mu\text{g m}^{-3}$), whereas MEK had lower concentrations (e.g. nondetectable – $13.4 \mu\text{g m}^{-3}$). These elevated values further manifest that the VOCs measured at the current sampling sites were contributed partially by mobile sources, because BTX exists in great amounts in gasoline. Beside the BTX, the VOC concentrations were lower and showed less variation between sampling sites. As also can be seen in Table III, none of the detected volatile organic compounds exceeded the regulatory standards and odor thresholds.

Compared to other sampling sites, the measured concentrations at the CY-3 site were generally higher. However, CY-3 was located on the downwind side of the Nylon-dyeing plant and is surrounded by mountains in the southeastern area. Therefore, vehicular emission sources were not anticipated to be as large in this area. We postulated that the wind from the northwest blew across the Nylon-dyeing plant, which emitted contaminants, and carried these pollutants to the region close to CY-3. In other words, the elevated VOC concentrations at CY-3 were due to fugitive emissions from the Nylon-dyeing plant instead of mobile source emissions. This hypothesis can be further confirmed by comparing the characteristic ratio for each sampling site as discussed below. Several researches have reported that the concentration characteristic ratio of toluene to benzene will be roughly 1–3, if the pollutants are contributed only by mobile sources (Pilar and Graydon, 1973).

Figure 8 shows that concentration characteristic ratio of toluene to benzene is in this range for UW-1, KS-2, and SR-4, therefore they were likely strongly affected by mobile sources. However, the ratio is as high as 17 for the CY-3 sampling site, which indicates that the emission source for CY-3 was different from the others. These results are consistent with the observation stated earlier; therefore, we suggest that the emission source(s) might be the Nylon-dyeing Plant.

4. Conclusions

Downwind SO₂ concentrations (i.e., KS-2) were always greater than the upwind concentrations (UW-1); however, it was also seen that the SO₂ concentrations were larger at both the upwind and downwind monitoring sites. This finding suggests that these contaminants must be coming from another large source upwind of UW-1. The Taiwan Coal-fired Power Plant (TCPT), located 50 km northwest of the FCFCCP, was hypothesized as a potential source of SO₂.

Although none of the detected sulfurous compounds exceeded the national limit, H₂S and CS₂ were occasionally present at levels higher than the odor threshold. Hence, the presence of these compounds probably triggered the residents to complain of the odor. To ease the concerns of some residents who thought that if they could smell an odor, then it is harmful, the FCFCCP has undertaken the installation of more air pollution control devices at their Rayon-fiber Plant.

The elevated characteristic ratio (i.e., toluene/benzene) for the detected VOCs indicates that most of the VOCs observed at CY-3 are emitted by the Nylon-dyeing Plant rather than by mobile sources. Because the detected VOCs all have concentrations several orders lower than the regulatory standards and odor thresholds, it may be concluded that the Nylon-dyeing Plant was not emitting VOCs at levels adverse to health.

In addition to continued monitoring at the FCFCCP in the future, the following actions are recommended: (1) Investigate the possibility of long range transport of SO₂ from the Taiwan Coal-fired Power Plant (TCPT) by performing an air dispersion model, and compare the results with the observed SO₂ concentrations. (2) Although the detected levels for most sulfurous compounds did not violate the ambient air quality standards for Changhwa County, the neurotoxicity of CS₂, which is classified as a group I organic solvent in Taiwan, requires careful consideration. It is suggested that more comprehensive research, such as epidemiological studies on the environmental impact of CS₂ emissions will be necessary.

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